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Preface

The combined forces of ISG (International Society of Gerontechnology) and the ISARC organization (International Symposium on Automation and Robotics in Construction) resulted in a successful world conference with 362 presentations and an attendance of 368 delegates from 32 different countries. The acceptance percentage of presentations amounted to 86%. 110 presentations published a full paper in a peer-review process. As many as 106 peer reviewers assisted the organizers. By January 21, 2013, more than 32,000 conference website visits had been counted.

Productive Exchange at ISG*ISARC2012

For the first time the bi-annual international conference of the ISG has been combined with another technical discipline: automation and robotics in construction. Exchanges between the two domains appeared especially lively and fruitful during moderated poster-and prototype events that took place at prime time in between coffee break and lunch time. Engineers, gerontologists and physicians of all sorts discovered their common grounds and taught each other. A clear similarity existed, technically speaking, between a robot handing over a cup of tea at home without spilling, and a robot placing a window frame correctly on a construction site. And how small is the difference between monitoring the whereabouts of floating objects in a sewer tube, and of persons in a room? Conference tracks, such as ‘Information technology’, ‘Robotics’, ‘Work – Leisure – Volunteering’, ‘Housing – Building – Daily living’ and ‘Communication – Management – Governance’ contained several contributions from both ISARC and ISG delegates. In contrast, the tracks ‘Automation’ and ‘Application systems – Realities’ were mostly devoted to the construction industry, while ‘Health – Comfort – Self-esteem’ and ‘Mobility – Transport – Travel’ had a strong gerontechnology taste. The plenary keynotes were attended by delegates from both domains and showed clearly future trends and societal concerns. Symposia became micro worlds in which viewpoints from different domains came along, presenters and participants formulated new scientific challenges together, with researchers and students broadening their understanding. Free communications came in 9 to 11 simultaneous sessions and were usually attended by a smaller but strongly interested audience. For the future, we recommend more combinations of conferences that are technically speaking much related, but culturally far apart. It will foster out-of-the box thinking in science as well as the creativity needed to solve current societal problems such as the adaptation to demographic, cultural and climatic change.

Abstracts

The abstracts of the conference ISG*ISARC2012 have been published in the International Journal Gerontechnology, 2012, Vol 11, No 2.

Proceedings

By this book we edited the full papers of the ISG*ISARC2012. The full papers are electronically to download by the site www.gerontechnology.info and www.iaarc.org. Finally, we would like to thank everyone whose support, commitment, enthusiasm, contribution and encouragement has made this congress possible.

Conference organizers,

Johanna E.M.H. van Bronswijk (ISG), Ger J. Maas (ISARC), Frans J.M. van Gassel (general secretary and treasurer).
Contents

Application systems - Realities: Keynote

Smart-BIM (Building Information Modeling)
B. de Vries, E. Allameh, M. Heidari Jozam

National Guidelines for Bridge Information Modeling and Automation
R. Heikkilä, J. Hovila

BIM functions for optimized construction management in civil engineering
H-S. Moon, H-S. Kim, L-S. Kang, C-H. Kim

Advanced Process Control for Infrastructure Building Processes
E. Viljamaa, I. Peltomaa, J. Hovila, R. Heikkilä

Application systems - Realities: Symposium

Markerless vision-based Augmented Reality for enhanced project visualization
F. Bosché, D. Tingdahl, L. Carozza, L. van Gool

Parametric modelling based approach for efficient quantity takeoff of NATM-Tunnels

Constructing as-is BIMs from progressive scan data
T. Gao, B. Akinci, S. Ergan, J. Garrett

Dynamic Simulation and Visualization for Site Layout Planning
K-Y. He, I-C. Wu

An integrated system for automated construction progress visualization using IFC-Based BIM
C-M. Kim, H-J. Son, C-W. Kim

BIM-Image-Based Indoor Localization Prototype
M-H. Tsai, Y-C. Hus, C-M Chiu, S-H. Chuang

Automation: Presentations

Automated prediction of condition state rating in bridge inspection
R.S. Adhikari, O. Moselhi, A. Bagchi

Digital Photogrametry in Investigation of Application membranes on the Surfaces of Cementitious Materials
P. Briatka, J. Gašparik

A Plane Tracker for AEC-automation Applications
C. Feng, V.R. Kamat

Automated quality excellence evaluation
J. Gašparik, M. Gašparík

Surveying of road slopes using mobile LiDAR
H. González-Jorge, P. Arias Sanchez, I. Puente, J. Martínez
Automated-driven concrete piling: Latest developments and experiments in Finland
R. Heikkilä, J. Hovila, P. Kipeläinen, E. Viljamaa, J. Törnvist, K. Nevala, T. Makkonen

Automating fabrication sequencing for industrial construction
D. Hu, Y. Mohamed

Shape recognition with point clouds in rebars
K. Ishida, N. Kano, K. Kimoto

Automated pipeline extraction for modeling from lasercanned data
J. Lee, C. Kim, H. Son, C-H Kim

RFID Indoor Location Identification for Construction Projects
A. Montaser, O. Moselhi

Self-growing Motion Mechanism for Inspection and Maintenance
S. Park, D. Hong

Non-destructive GPR evaluation of underpass arch-shape structures
M. Solla, H. González-Jorge, P. Arias Sanchez, H. Lorenzo

Ultra-pervasive district monitoring for water leak detection
M. Vaccarini, B. Naticchia, A. Casolaro, A. Carbonari

Communication - Management - Governance: Symposia

Gerontechnology acceptance by older Hong Kong people
K. Chen, A.H.S. Chan, S.C. Chan

Aging and Architecture Design Aids by Integral ‘Age-Proof’ Housing Models
P. Schmid, G. Pal-Schmid

Communication - Management - Governance: Other Presentations

A Bayesian Model for real-time safety management in construction sites
C. Argiolas, A. Carbonari, F. Melis, E. Quaquero

Assessment of sustainable construction in Lebanon
R.E. Awwad, K. Elkhoury

The Impact of ICT Use on Loneliness and Contact with Others among Older Adults
S.R. Cotten, W. Anderson, B. McCullough

BIPV prototype for the solar insolation calculation
M.K. Dixit, W. Yan

SIMPPLIT: Ensuring technology usability for the elderly
J.V. Durá, J. Laparra, R. Poveda, R. Marzo, A. Lopez, C. Bollain

Risk communication design for older adults
V. Garg, L. Huber, L.J. Camp, K. Connelly

Environmental Modeling for the Optimal Energy Control of Subway Stations
A. Giretti, M. Lemma, R. Larghetti, R. Ansuini

Change and contract management modules of intelligent-program management information systems (i-PgMIS) for urban renewal projects
C.T. Hyun, Y.W. Cha, R.Z. Jin, M.J. Son
Refurbishing homes for elderly using BIM and CNC technology
K. Iturralde

The adoption of Industrialised Building System (IBS) construction in Malaysia: The history, policies, experiences and lesson learned
K.A.M. Kamar, Z.A. Hamid, I. Din

MDA-based facility management applications under BIM
C-Y. Lin, C-C. Chou

Applying building information modelling in environmental impact assessment for urban deep excavation projects
S.R. Lu, I.C. Wu, B.C. Hsiung

Automation of modular design and construction through an integrated BIM/lean model
M. Moghadam, G. Singh, M. Al-hussein

Fuzzy Set-based Contingency Estimating and Management
O. Moselhi, A. Salah

The Future of Assistive Technologies for Dementia
C. Peterson, N.R. Prasad, R. Prasad

Health - Comfort - Self-Esteem: Symposia

Tele-operated service robots for household and care
M.P.W.J. van Osch, D. Bera, Y. Koks, K.M. van Hee

Health - Comfort - Self-Esteem: Other Presentations

Reducing shoulder injuries among construction workers
A. Alwasel, K. Elrayes, E. Abdel-Rahman, C. Haas

Assessing assistive technology outcomes with dementia
C.B. Peterson, N.R. Prasad

When older adults start and stop to use technologies: Long term study on technology usage, computer attitudes and cognitive abilities of Japanese older adults
J. Zhang, H. Umemuro

Housing - Building - Daily living: Symposia

Alzheimer’s patient activity assessment using different sensors

Facilitating the adaptability of buildings through the separation of components
S. Isaac, F. Sadeghpour

Housing - Building - Daily living: Other Presentations

Prediction of project cash flow using time-depended evolutionary LS-SVM inference model
M-Y. Cheng, N-D. Hoang, Y-W. Wu

A survey of ergonomic parameters of shoppers
S. Farivar, H.S. Naeini
Sonification system for aging Taiwanese people
C.F. Huang, E.J. Lin

Application of queuing theory in construction industry
Č. Jaršky, V. Usmanov

Laser Positioning System Using RFID-tags
S. Sakamoto, N. Kano, T. Igarashi, H. Tomita

Information technology supporting daily activities of seniors
D. Šimšík, A. Galajdová, D. Siman, M. Andrášová, R. Balog

“The Desirable Scale”: Weighing social quality of assisted living facilities
T.G.M. Spierings, D.J.M. van der Voordt, M. van Biene

Speech-based interaction in an AAL-context
M. Vacher, F. Portet, S. Rossato, F. Aman, C. Golanski, R. Dugheanu

Aging-in-Place: A Challenge towards Sustainable Planning in the Dutch Housing Market
A.A.M. van Vliet

Information technology: Other Presentations

Image-based Retrieval of Concrete Crack Properties
R.S. Adhikari, O. Moselhi, A. Bagchi

Dynamic planning of earthmoving projects using system dynamics
H. Alzraiee, O. Moselhi, T. Zayed

Challenges of Identifying Steel Sections for the Generation of As-Is BIMs from Laser Scan Data
E.B. Anil, R. Sunnam, B. Akinci

Bid Decision Making with Prospect Game Theory
M-Y. Cheng, C-C. Hsiang

Data mining and statistical analysis of construction equipment failure
H.Q. Fan

Suction force of blowing fans on various surface shapes of outer wall
Y-B. Ham, B-J. Lim, J-H. Noh, J-H. Park

Integrating of optimization and data mining techniques for high-speed train timetable design considering disturbances
T-W. Ho, T-C. Chen, C-C. Chou

Is color an intrinsic property of construction object’s representation?
Evaluating color-based models to detect objects by using data mining techniques
N. Hwang, H. Son, C-W. Kim, C-W. Kim

Combining automatically and manually collected data for project monitoring and control
S. Isaac, R. Navon

Cost Effective Sensors for Automated Progress Measurement and Management (APMM)
Y. Jung, J. Ha, T. Ju, S. Kang

New sampling scheme for neural network-based meta-modelling with application to air pollutant estimation
H. Wahid, Q.P. Ha, H. Duc
Evaluation of various visualization forms for facility operation and maintenance
X. Yang, S. Ergan

Mobility - Transport - Travel: Other Presentations

Integrated approach for older adult friendly home stair-case design
M. Afifi, B. Parke, M. Al-Hussein

Efficacy of different insole designs on fall prevention of the elderly
Y-T. Liu, K-T. Liu, S-W. Yang

Gait rehabilitation with a robotic dog
M. Naganuma, E. Okhubo, R. Kimura, M. Watanabe, N. Kato

A generic method for the assessment of smart walkers
P. Rumeau, V. Pasqui, N. Vigourou

The mechatronic shoe: A new rehabilitation tool for improving mobility
D. Šimšík, A. Galajdova, M. Gorlicky, B. Jobbagy, R. Balog

Robotics: Other Presentations

Flowing matter: Robotic fabrication of complex ceramic systems
M. Bechthold, S. Andreani, J.L. Garcia del Castillo, A. Jyoti, N. King

Robotic Tile Placement: Tools, Techniques and Feasibility
M. Bechthold, A. Kane, J. King, P. Michalatos

Towards Robotic Assisted Hygienic Services: Concept for Assisting and Automating
Daily Activities in the Bathroom
T. Bock, C. Georgoulas, T. Linner

Co-adaptation of Assistive Mobility Devices and Residential Functions
T. Bock, T. Linner, C. Georgoulas

Modeling of a Mobile Manipulator for Redundancy Resolution
B. Chu

A new generation of collaborative robots for material handling
E. Gambao, M. Hernando, D. Surdilovic

A novel MiniOn Agent Assisted Robotic Kitchen Platform
C. Georgoulas, T. Linner, T. Bock

Vision controlled robotic furniture system
C. Georgoulas, T. Linner, T. Bock

An easy handling system for installing heavy glass using human robot cooperation
M.S. Gil, S.H. Kim, H.G. Kim, M.S. Kang, C.S. Han

Development of cleaning system installed in horizontal moving system for maintenance of
high-rise building
J. Huh, S. Moon, S. Kim, D. Hong

Maintenance robot for wind power blade cleaning
M. Jeon, B.G. Kim, D. Hong
Height Estimation of Gondola-typed Facade Robot
D.Y. Kim, H. Sun, C-W. Park

Advanced Building Engineering Deploying Mechatronics and Robotics in Architecture
T. Linner, C. Georgoulas, T. Bock

A Multi Robotic Assistant System (MRAS): A development approach with application to the ageing society
T. Linner, C. Georgoulas, T. Bock

Assessing design features of a graphical user interface for a social assistive robot for older adults with cognitive impairment
M. Pino, C. Granata, G. Legouverneur, M. Boulay, A-S. Rigaud

Tunnel boring machine positioning automation in tunnel construction
X. Shen, M. Lu, S. Fernando, S.M. AbouRizk

Work - Leisure - Volunteering: Other Presentations

Optimized Acceleration of Repetitive Construction Projects
I. Bakry, O. Moselhi

Virtual Reality for Persons with Dementia: an Exergaming Experience
M. Colombo, E. Marelli, R. Vaccaro, E. Valle, S. Colombaril, S. Garolfi, S. Fossi, A. Guaita, E. Polesel

Estimation of job-site work progress through on-site monitoring
A. Giretti, A. Carbonari, G. Novembri, F. Robuffo

Engaging isolated seniors and reducing caregiver burden
C.E. Grammer, W.T. D'Silva, C. Gardner, L. Canlas

Site layout optimization for caisson structure fabrication
C. Kim, H. Kim, T. Park

Developing the ‘mStick’ concept: experiences and impacts
P. Kuosmanen, S. Peakarinen, K. Kempas, H. Melkas, R. Valve, A. Karisto

Estimation with applications to dynamic status of an excavator without renovation
S.H. Lee, M.S. Kang, D.S. Shin, C.S. Han

Introducing and applying a modified AHP (Analysis Hierarchy Process) to analyse productivity at the construction site

An object library approach for managing construction safety components based on BIM
J. Li, Z. Hua

Positioning of human resources in a construction environment using Zigbee
M. Raj, K. Varghese

An optimized operation algorithm for twin or multi-cage lift systems for high-rise construction sites
J-H. Shin, S-W. Kwon, M-N. Lee, D-Y. Moon

An integrated automatic wall concreting system
A. Więckowski

Static compensation ZMP algorithm preventing tips-over of a tele-operation excavator
B-H. Yu, K-Y. Park, K-D. Lee, C-S. Han
Smart-BIM (Building Information Modeling)

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Purpose After a long period of international research and development, BIM has become mature. Many tools support the BIM process, or at least they claim. BIM not only offers opportunities for the Architectural Engineering and Construction industry, but also for the client. In this paper we don’t focus on the professional client, but on the client of a building assignment that act as the end-user. Involvement of the end user in the design process has been advocated by many scholars and designers, but has so far only marginally been adopted in practice. The importance of user participation is demonstrated by the lack of success of smart technologies in new housing or in renovation. Particularly elderly people resist accepting these technologies in their home environment, although they could benefit from these technologies to improve comfort and health care. As a result of poor understanding of these new technologies by both designers and end users, researchers observe that there is a mismatch between user demands and smart technology usability. Hence, this paper is an attempt to improve the role of users in the design process in two ways. Firstly, by adding the missing components of smart technology to current BIM model libraries. Secondly, by developing a virtual model in which users can interact with the smart technologies and configure their preferred layout. The final results are interesting not only for technology developers but also for housing designers who aim at improving the quality of life in future housing for aging society.

Method For a better understanding of BIM, a historical perspective is taken in this paper. The initiatives from different research institutes are discussed and how they affected each other. The up-take by the software industry is highlighted and their delicate relationship with science. In today’s design process BIM systems support spatial design that is accommodate by smart technology. Usually this smart technology is added after the spatial design in the final design stage by the installations expert. In our research we want to turn this process around; the smart technologies are accommodated by spatial design. Therefore we develop a design system with a library of smart components such as smart wall, smart kitchen and smart furniture. The difference between smart technologies and standard building components is that smart technologies interact with the building users. BIM allows for realistic visualization of designs in an early stage. In our prototype system, clients are presented a virtual space with a wide range of smart technologies. After being introduced to these technologies, the client expresses how these will fit within his/her activities. Following he/she can experience in the virtual model how smart technologies react when activities are executed.

Results & Discussion A prototype system is presented that allows clients such as elderly to experience smart technologies. In contrast with traditional design it does not start from the spatial layout but from the activities that should be accommodated supported by smart technologies. We expect that fundamentally different layout will emerge from this approach. Although no experimental data are available yet, some first experiences will be discussed.

Keywords: BIM, smart technology, client support

INTRODUCTION
After a long period of international research and development, BIM has become mature. Many tools support the BIM process, or at least they claim. BIM not only offers opportunities for the Architectural Engineering and Construction industry, but also for the client. In this paper we don’t focus on the professional client, but on the client of a building assignment that act as the end-user. Involvement of the end user in the design process has been advocated by many scholars and designers, but has so far only marginally been adopted in practice. The importance of user participation is demonstrated by the lack of success of smart technologies in new housing or in renovation. Particularly elderly people resist accepting these technologies in their home environment, although they could benefit from these technologies to improve comfort and health care. As a result of poor understanding of these new technologies by both designers and end users, researchers observe that there is a mismatch between user demands and smart technology usability. In today’s design process BIM systems support spatial design that is accommodate by smart technology. Usually this smart technology is added after the spatial design in the final design stage by the installations expert. In our research we want to turn this process around; the smart technologies are accommodated by spatial design. Therefore we develop a design system with a library of smart components such as smart wall, smart kitchen and smart furniture. The difference between smart technologies and standard building components is that smart technologies interact with the building users. BIM allows for realistic visualization of designs in an
early stage. In our Smart Design system, clients are presented a virtual space with a wide range of smart technologies. After being introduced to these technologies, the clients express how these certain technologies will fit within their scheme of daily activities and give their requirements and feedbacks while performing tasks in the virtual model.

In our view, Smart-BIM is composed of Smart Design system using Smart technologies. Hence, the outline of this paper is as follows. First, we describe what the features of Smart technologies are and how they are related to existing BIM components. Following we present the Smart Design system functionality and how it can support the client to experience interaction with the smart technologies. Finally, we draw conclusion on the consequence of Smart-BIM for the design process and the building industry.

**SMART TECHNOLOGIES**

BIM is not possible without standardization of building components. Many building component libraries have been developed for different aspects of the building design, such as spatial design, structural design, installations, etc. Often these libraries are included in Architecture, Engineering and Construction (AEC) tools, or they are provided by product suppliers. To support the quest for data exchange models between different AEC tools, standardization efforts have focussed on building components. The most widely spread ISO certified building component library is the Industry Foundation Classes (IFC) standard. Building component libraries like IFC have developed from traditional catalogues of building products. The main challenge is to define a parameterized geometrical description and to define the additional attributes for material, cost, etc. Building components libraries are intensively used in the AEC industry today and thus have proven their success. However, since they are based on traditional building components, they also prohibit fast adoption of new building components.

Smart objects contain their own functions in their property set to interact with users and other objects. Defining the property set of these smart objects needs an understanding of their function in real situations. In the following, three types of smart objects, their functions and features are introduced:

**Smart Kitchen Table** is a normal table with supplementary attributes of:
- Touch Screen Surface which allows the size of hot zones and temperature to be adjusted by user. It allows the user to browse the internet on the surface.
- Multimedia networking which let different electrical appliances communicate with each other. Internet, recipe database, television as well as other building services can be operated and controlled from it.
- Dynamic Table Top Interface made of wireless power which makes it possible to have no preset cooking zones. Cooking takes place anywhere, anytime on the table. Energy will follow the devices as they move around the surface, and so the interface will be displayed on the table top surface.

**Smart Wall** combines the concept of both TV and Computer together integrating in a wall. This revolutionary piece of equipment can be used in either a fixed or temporary environment, allowing the user to create an interactive working and living space in almost any location. The objective of this Wall is to serve the following attributes:
- Changeable scenery system which creates different scenery on the wall by adding the elements of entertainment and sensitivity to the wall.
- Interactive electronic surfaces on the wall represented by a touch-sensitive information device.
- Internet connected system enables several tele-activities such as tele-educating, tele-caretaking, tele-team working. The goal is to support two or more persons, in parallel or sharing the whole display space. It also covers virtual communications relying on more natural gestures.
- Environmental control system which is connected to smart context. Hence, Smart Wall environment reacts to users’ function by adapting the HVAC conditions and natural/artificial light for a personalized room ambience. Also it is connected to the other home digital devices; users can manage other home appliances through the Smart Wall.

**Smart Furniture** has different user interface and interaction styles from current furniture and computers which have standard desktop PC, single user display, keyboard, and mouse. Computers are going to be embedded in tables, seats and mobile devices. They are also connected to each other and to the whole Home Network. So the data can easily transfer among different furniture. The common features of Smart furniture can be introduced as:
- Flexible and movable,
- Intelligent and aware of users’ need and preferences, due to several sensors,
- Responsive to users’ activity, due to being programmable,
- Interactive, due to equipping with touch screen surfaces or LCD,
- Multifunction, due to supporting different virtual activities, entertainment activities, relaxing, work related activities also managing other device and environmental conditions, such as HVAC.
All the objects and technologies inside the Smart Home support people carrying out their everyday activities, tasks and rituals in an easy, intelligent and interactive way. Accordingly, the difference between a ‘normal’ library component and a smart library component is the interaction between the component and the building users. If we take as an example the ifc-Wall Standard Case and its property set, this wall type will contain a geometry description and a list of properties such as: Acoustic Rating, Fire Rating, Combustible, Surface Spread of Flame, etc. The wall geometry and properties are determined in a long standardization process by the most common wall types that are found in today’s building sector. In case of a smart wall, there are hardly any precedents. The definition of a smart wall should not only describe the geometry and material, but also the interaction with its intended users. This description can be static, but then the added value in the design process is limited. We think that designing a smart building requires interactive building components. Interactive building components respond to touch, remote control, motion detection, or whatever method is used to interact. Interactive building components are often integrated components consisting of constructive parts and embedded technologies. These embedded technologies can range from LCD screens to micro sensors.

Digital representations of interactive systems are not entirely new. On the internet we can find many examples (often implemented in Flash) of commercial products that one can view and virtually operate by clicking on buttons or hot spots. This type of information sharing is not only more attractive but also gives a better sense of reality, then plain technical data. In this example, interaction is established through mouse-clicks. For more realistic evaluation of a virtual building model, the smart building components should be able to receive input from multiple sensors and to act accordingly. Because today information about multi-sensory interaction is still rare, standardization of these new technologies is a long shot. But for existing interface technologies like remote control, implementation of a smart building component is very well possible. Technically, digital building component libraries need to be extended with interactive 2D or 3D models to turn these into smart components. In current digital libraries, we can also find multiple representations for the same product. Multiple representations have proven to be useful for different levels of detail and for hiding irrelevant information. An interactive model can be seen as yet another view on the same product. An example of interactive digital model of a smart wall is presented in Figure 1.

Fig.1. Interactive digital model of a smart wall: Each smart object contains several smart components with a property set.

A smart object consists of several smart components with a property set that specifies its capabilities to respond to user activities. Figure 1 shows a smart wall with three interactive surfaces as smart components. A smart wall ‘senses’ the activities that are executed and it will act accordingly for instance by switching on screens for different purposes such as tele-communication, tele-shopping, entertainment, etc.

SMART DESIGN

As any smart home will be eventually used by end users, providing a method to enhance user participation for interaction manipulation is indispensable. Our Smart Design system applies the user-centered approach to let users interact with the objects and experience smart living in a new home setting. Using VR technology, the platform is capable of visualizing smart technologies and performs real-time interactions with the home. This Smart Design system is based on a task-based model in which end users interact with the system and experience how smart objects respond to typical domestic activities.

This proposed design system aims to collect information on people’s appreciation of smart technologies. The system not only supports design of home interiors but also elicitation of activities that a user wants to perform within the contextual conditions. This integration aims to facilitate both end-users and designers to understand how the users’ activity will be accommodated in the given home setting. There are other researches which aim to simulate and predict occupants’ activities in the given building and evaluate the building performance including evacuation, circulation, building control system.
While many of them focus on office environments like Tabak’s research and non-smart environments, our proposed design system can be used to experience not only how a smart building will look like but also how users will interact with such a kind of environment based on activity contexts. It improves users’ understanding on the design, help them specify their activities in the given new home setting and increase their involvement in the communication with designers. The system also let designers evaluate the design (in terms of spatial properties and technology functions) and collect users’ feedback of the design by a task-based interaction between user and building.

Since the relation between the user and the building is mediated through the spaces where the activities take place, human–space interaction plays a key role in Smart Design system. Behaviour of the users and their response to technology is critically dependent upon the environment and context in which information is presented or requested. The most popular assessment instruments in use today for studying the activities of people in natural settings are self report recall surveys, time diaries, direct field observation, and experience sampling. Developing daily activity specifications could be helpful method to have a more realistic interaction. Oxman et al introduced three design paradigms to induce interaction process with virtual environment: task-based design, scenario-based design and performance-based design. Implementing each of these paradigms enhances users experience in virtual environment and improves the human sense of “being there”. While scenario-based design and performance-based design are based on specific predefined situations, task-based results could be closer to users’ real reactions. Task-based process enables users to imagine the scheme of their daily activities in the task context and react accordingly. It also enables context reaction toward users’ interaction and functions as found in physical smart space. Finally, an improved understanding of smart technology usage is expected from both end users and designers through this task-based interaction.

Applying this Smart Design system needs Smart BIM, that is, a model that includes smart objects and users tasks. Smart objects are part of a building model. A smart object consists of one or more smart components that have specific capabilities. Examples of HasCapabilities are: Displaying, Heating, Lighting, etc. A user will execute many tasks in the home environment. Each task is determined by the combination of a zone in the building model and an activity from the activity list. The activity list contains two types of activities: (1) Main activity and (2) Secondary activity. A task always contains one main activity (e.g. cooking) and may contain one or more secondary activities (e.g. TV watching). An activity has one or more NeedCapabilities. Examples of NeedCapabilities for activity cooking are: Baking, Recipe displaying, Air cleaning, etc.

The structure of this Smart Design system is presented in Figure 2.

The interaction between user and its smart home is established through matching the NeedCapabilities with the HasCapabilities. In our prototype Design Systems this matching procedure is a simple rule-based system, because it aims to experience smart objects, but avoid too much complexity for the user. In reality, however this matching process is performed by an intelligent home system that lets smart technologies communicate with each other.

In a smart design session, the designer will first create the home interior like with any CAD program but with use of smart objects. After the client is satisfied with the spatial design, the designer will create specific zones in the home and enter some general information about the client. In discussion with the client, the designer determines the tasks that the client wants to perform in his/her new home. For each task, the client makes a selection from the activity list and a selection from the available zones. Then the smart design is ready for design experience by the client. The client is requested to navigate through the digital building model. At any spot in the home, he/she can execute a task. Therefore, he/she can use a virtual mobile phone to select a predefined task. After task selection, the smart objects will respond. The type of response is determined by the rule-based system, because it aims to experience smart objects, but avoid too much complexity for the user.

As an example, the user will navigate to the smart kitchen table (Figure 3). In the zone, the virtual mobile phone will pop up. After selection of main activity= cooking and secondary activity= watching TV, the kitchen table will present a cooking area. At the same time, one of the TV screens nearby scans the TV channels for the latest news and another one shows a web site with cooking recipes for users’ diet. Because the person is an elderly, the floor sur-
face will be sensible for falling and the lighting is set to a high level for a better vision.

In discussion with the designer, the client expresses his/her appreciation, misunderstanding, disapproval, etc, and makes suggestions for improvement of the design.

CONCLUSION

We believe that smart-BIM will change the building design and the building process. Only if smart objects are part of the CAD libraries, smart objects will become a natural choice in the design process. Like normal building objects, smart object are a representation of reality. Although today computer systems can do wonderful things, the perception of space and material through virtual models is limited. Likewise the perception of smart objects will be limited but nevertheless very valuable. Experiencing real-time response in a virtual model adds to the understanding of the smart home environment. The building process will change because in a smart design process, it is impossible to design without the involvement of the client/user. Participatory design has not been very successful so far, but for smart design it is a precondition. At various stages of the design process, user’s acceptance needs to be evaluated. User involvement through shared virtual models is possible today and may provide designer and engineer with much new information upfront.

We imagine that the smart design system can be used for other purposes, such as: measuring user preferences, space utilization analyses, user behavior research, etc. In our future research, we will investigate these possibilities and extend the library of smart objects.

References

National Guidelines for Bridge Information Modeling and Automation

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Purpose
National bridge information modeling guidelines have been developed in Finland at the behest of the Finnish Transport Agency. The aim was to set, for the first time, national standard of producing and utilizing 3D-information modeling and automation in bridge engineering in Finland. 

Method
In the guidelines, the terminology of different main design phases of bridges and information models is introduced. More specific information model contents and technical guidelines are then determined. A comparison is made between the Finnish guidelines and the draft Norwegian modeling guidelines.

Results & Discussion
In Finland and Norway these guidelines aim to promote the use of 3D-modeling and automation in the infrastructure, including bridges, roads, and railways. There are many reasons why these types of guidelines are necessary for the industry. More international collaboration will be needed in the next development phase to arrive at comprehensive and useful guidelines and standards.

Keywords: 3D, information modeling, bridges

INTRODUCTION
Since 2001 there has been done continuous research and development work to develop the processes of bridge engineering and construction in Finland. Active work has been done in the projects called Intelligent Bridge, 5-D Bridge and 5-D Bridge2. This report introduces the results of the last 5-D Bridge2 (Development of automation into construction, repairing and maintenance of bridges) project realized in 2007-2010.

In one of the part projects of the 5-D Bridge2, i.e., Bridge Finland, general product modeling directions and specifications were developed. The next test phase is scheduled to start from the beginning of 2011. In PPP5D project, the utilization methods and possibilities of 3-D product modeling and 3-D surveying methods were modeled in a general level. In Custom Componenets project, many useful design tools were developed for bridge designer. In 3-D GPR project, the measuring methods of Ground Penetrating Radar in 3-D were studied. The Crusell Bridge in Helsinki City was the most important test case of 3D product modeling and the utilization of this information model in construction work phase. In 5-D Vt8 project, the integration of road design and bridge design was studied and tested. In addition of these part projects, the research and development work was done in several other part projects of 5-D Bridge2, of which the work by Tekla Oyj in the development of Tekla Structures software, the study of Revit Structure software by Ponvia Oy, and the development project of Destia to develop the method and process model of Design-Build model utilizing product modeling and automation features was done.

There still remain many lacks and development tasks in the development of 3-D data modeling and automation in bridge engineering. The tested design software, applications and tools are not yet ready and completed, instead they include many different lacks and problems. The utilization of product modeling more widely should be supported and even demanded by owners. The first data modeling specification developed in the 5-D Bridge2, is one of the important steps towards that direction. The information transfer and communication between road design and bridge design should also be easy and efficient.

Fig.1. An example - a completed detailed product model of a bridge. The model should be ready for fully utilization in the construction processes by bridge contractor (Tekla Structures, WSP Finland Oy).

In Finland, important research and development work will be done in the new RYM Shok PRE program and the InfraFINBIM work packet, in which so called Bridge Automation project by University of
Oulu will be realized. Also possibilities for international research and development work will be better than earlier.

Fig.2. An example - the digital terrain model of a bridge construction site has been imported to the Bridge Modeling software (Tekla Structures, Tekla Oyj).

Objective
The objective of Bridge Finland subproject was to develop national bridge information modeling guidelines so that the work methods and models produced would be more uniform, and on the other hand still try to stay as neutral as possible to allow fast development of the field and to not block competition and introduction of new innovative methods of utilizing and producing the models.

DEVELOPMENT OF THE MODELING GUIDELINES
The study was executed by University of Oulu and A-insinöörit Oy. The development project was started by studying and collecting any of the information how the different bridge design offices and companies been participated in the research, have done bridge design modeling. There were in all eight (8) different companies in this work (Ponvia Oy, Finnmap Consulting Oy, A-Insinöörit Oy, Siltanylund Oy, Ramboll Finland Oy, Destia Oy and Oy VR-Rata Ab, Tekla Oyj) and two of the main owners of the bridges in Finland, Finnish Transport Agency and the Public Works Department of Helsinki City. A work part was done to study and develop the numbering of the different bridge parts and the logic included. Two different modeling software was studied and considered, i.e., Tekla Structures and Solidworks. The most important general guidelines were identified first, a draft for the public guidelines was created and commented by the other partners included, and finally published by the Finnish Transport Agency.

RESULTS
The final version of the National Guidelines for Bridge Information Modeling can be uploaded from the web site of the Finnish Transport Agency:


The guidelines contains following chapters:
(1) Description of modeling, model detail levels and model utilization in each of the design phases of a bridge. The phases are preliminary design, general design, bridge design, construction design, and renovation planning.
(2) Information model contents, technical guidelines discussion, such as coordinate systems, numbering of parts and model detail accuracy levels. Also description on how to report the status of a model and discussion about the as-built model.
(3) Design blueprints and how the 3d modeling process affects them.
(4) Quality control, how it should be done by the design office and what materials will be needed by the public administration to check the plans.
(5) Model utilization at work sites.
(6) Model handovers, what are the legal points related to handing over the models to the different parties in a bridge construction project.
vers to third parties, and what information will the as-built model contain, will as-built measurements and other information be inserted into the model.

CONCLUSION
National bridge modeling guidelines will speed the transition of the public administration and the private sector to 3-D modeling and . Overall, the transition to using 3-D information models for bridge construction projects is clearly inevitable as more and more bridge projects are being designed via information modeling in Finland. Nearly every design consultant office is gearing for information modeling. Also general contractors are frantically working to develop their processes towards using data from information models and to reduce waste in construction work.

Related to the new guidelines, there is a large research project, called RYM PRE (Process Re-Engineering) at active phase in Finland. The aim is to develop wider building information modeling (BIM) guidelines and requirements to the all extension of infra construction activities in Finland. In addition, there are a group of work packets, where the aim is to continue the development work of the BIM guidelines for building construction sector. Also the research collaboration of BIM between infra and building sector has been studied and is about to start.

The future work is focused to test the guidelines for bridge modeling, based on the experiences got to develop the next version of the guidelines, combine that together with the guidelines for modeling of roads, railways, tunnels and dredging process, which are to be developed within RYM PRE InfraFINBIM research project. This research group is very interested in and is looking for international collaboration with other countries in this work.

More information can be found from the website: http://www.rym.fi/en/programs/builtenvironmentprocessreengineeringpre/

References


BIM functions for optimized construction management in civil engineering

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Purpose  The aim of this study is to suggest configuration methodologies of active building information model (BIM) functions that enable to practically control limitations by optimizing schedule overlapping linked to its space models after analyzing workspace conflict analysis for a bridge model. This study also suggests development methodologies of active BIM-functions, linking an optimized method and improved strategies of future BIM-operation model through an analysis of limitations of a passive BIM-operation system for architectural projects.

Method  The existing BIM-system manually performed a simplified comparison review of 3D-shapes and its virtual reality (VR) analysis with visual manipulation of 3D-models in a virtual environment. Such BIM functions require a separate analysis process to organize BIM-output data as reprocessed business data. This has many limitations when directly utilizing the visual information produced by commercial BIM-systems as practical operation data. Accordingly, this study develops functions of an active BIM-system so that the managers can directly analyze practical requirements by integrating an optimized analysis algorithm with the BIM-system to improve the passive BIM operation environments. As a method of configuring the active BIM-functions, an optimized algorithm for establishing resolution strategies for workspace conflicts is constructed. As functions for supporting active BIM-operations, this study utilizes fuzzy and genetic algorithm (GA) approaches. These approaches will be used to develop visualized risk assessment model and workspace conflict optimization model based on active BIM.

Results & Discussion  By enhancing fragmentary analysis functions of simplified 3D-models with the development of an active BIM-system, the BIM-system can utilize output information derived from a process of analysis, evaluation and control of the BIM-models as a practical operation information model for both design and construction phase. Therefore, it is expected that an active BIM can simplify data analysis and the system operation process for managers with virtual object models and expand the active BIM-system to the life cycle of civil engineering projects.

Keywords: active BIM, passive BIM, optimization, risk assessment, workspace conflict

INTRODUCTION  Recent trends in BIM (Building Information Modeling) are that it has been applied as a passive process that is centered on a simple visualization analysis process. Existing researches are also focused on the development of IFC (Industry Foundation Classes) for securing interoperability between information for building project1, development of 4D CAD system for sequential visualization of 3D object over time2, and an integration of design and manufacturing and construction3. In addition to the BIM system, such as Navisworks, Revit Architecture, these researches require a separated procedure in order to control schedule, workspace and risk level after operating the BIM system, which includes modeling software, 4D CAD, and structural analysis.

Unlike such researches, this study attempts to develop a BIM-based system for controlling all the construction data, such as schedule and risk within a single BIM system based on a 4D CAD platform without requiring a separated control procedure or expert knowledge. Therefore, for the more advanced BIM in the future, active BIM environments that could provide such project management data as schedule, resources, costs, space and risks should be established4. This study improved the existing BIM operation system and suggested a methodology that could develop an active BIM operation strategy for civil engineering projects. In order to do so, this study analyzes problems of a passive BIM and derives an improvement strategy of the active BIM that is based on the 4D CAD platform. This study suggests the active BIM functions using ‘Genetic Algorithm’ and ‘Fuzzy Theory’, which are utilized for schedule optimization, workspace optimization and risk analysis. Those functions are simulated with 4D objects using V-CPM, which is developed by the research team (V-CPM)5.
The purpose of this study is to develop a methodology and a system that can improve passive BIM environments and eventually establish 4D CAD based active BIM environments. An active BIM system can secure a project's productivity and safety through a schedule optimization that reflects on-site conditions; therefore, it is expected that the system will be effectively used as a decision-making tool for construction project management. Besides, the suggested active BIM operation system can be easily utilized without requiring a distributed control procedure or expert knowledge within a single system.

“PASSIVE BIM” VS. “ACTIVE BIM” FOR CONSTRUCTION INDUSTRY

Most of BIM features including 4D simulation are focused on the simple visualization functions of numerical construction data. Project managers can identify the visual status of construction project by current BIM functions. That is, they cannot provide an analytical data, such as an optimal schedule plan considering site conditions and activity’s constructability that can assist project managers. Besides, the current BIM system requires a separated analysis process in order to control project data risk after its visual simulation. If those current functions are classified by passive BIM system, the active BIM system has various decision making functions to provide the optimal plans of the project. Using the suggested workspace analysis method by 3D object and simulation method by 4D object, a project manager can have an optimal schedule plan that the workspace conflict is minimized. Those methodologies can be used for the active BIM system which may be a representative construction management tool.

Civil engineering works require a methodology for the establishment of an active BIM that could manage various construction types (i.e. wide-area works, earthworks, combinational works, etc.) and minimize diverse related risks. Fig. 1 shows how an active BIM model is built from a passive BIM model. Controllable factors during the construction phase in the building works include schedule, costs, resource, workspace dependent constructability and safety. Under the current BIM environments, these factors have not been effectively controlled, and there were, consequently, a number of restrictions to active utilization of BIM for such critical processes as optimal schedule management and workspace conflict management. Especially, if such critical functions as schedule conflict optimization, workspace conflict optimization, risk assessment and optimal equipment layout are available under the BIM environments, these functions will become fundamental functions of an active BIM system.

ESTABLISHMENT OF ACTIVE BIM FUNCTIONS DURING THE CONSTRUCTION PHASE

Workspace conflict optimization methodology

The purpose of a workspace conflict optimization function is to secure the safety and constructability of various construction works. This function can search for an optimal schedule model that minimizes workspace conflicts between the two schedules performed concurrently in neighboring spaces. That is, this function provides essential data for an optimal workspace plan during the construction phase. Fig. 2 shows a GA-based optimization methodology to minimize workspace conflicts.
For the optimization of workspace conflicts, creation process of a workspace model should be preceded, and a schedule conflict ratio can be computed through sequential check of schedule conflicts for a basis schedule and a conflict schedule. Then, the adjacency of mutual workspaces for each activity with schedule conflicts should be reviewed to derive certain workspace conflict results. These results can be obtained by searching for particular distance values that are less than the designated tolerance values. Throughout these procedures, those activities with schedule and workspace conflicts can be detected. However, there should be optimization processes that could minimize the conflict duration of fixed workspaces in order to resolve the workspace conflict results.

Based on the workspace conflict results, those schedule data linked with a workspace model can be extracted. These schedule data should be optimized through GA for the search of certain results with minimum schedule conflicts, therefore optimizing the workspace conflict duration. Here, workspace conflict optimization can be performed by controlling the schedule overlapping duration. Since each activity has own total float (TF), the conflict status is solved by changing activity within the total float maintaining activity relationships with GA operation. Then, the optimized schedules will be updated into a workspace model, and a new optimal workspace-planning model can be created. Workspace conflicts created from the planned 4D model are optimized and then compared with those from the new 4D model, thereby allowing workers to check conflict management conditions. In this way, a schedule-based workspace optimization can be executed during the construction phase.

Risk visualization methodology
A risk assessment model is designated to quantify such project risk factors as project period, costs and work conditions and interface the quantification results with a 4D model, therefore visually assessing a certain risk level for each construction type. For the visualization of risk factors, a series of risk analysis procedures should be integrated into a 4D model. Risk priorities for such risk factors as project period, costs and work conditions are determined through AHP (Analytic Hierarchy Process) and applied to a risk assessment algorithm by Fuzzy analysis method. This can visually analyze risk levels for each activity. In addition, diverse analysis conditions that multiply project period, costs and work conditions can be reflected into those risk levels. The risk levels of each activity can be categorized into a risk impact (P1: Very Low ~ P5: Very High) and a risk probability (I1~I6), thereby enabling a project manager to discretely select a certain linguistic variable for each activity type. This variable can vary according to each activity’s characteristics. These variables will be factored into a Fuzzy membership function in order to compute risk levels, which will be finally set by GMV (Generalized Mean Value). These risk levels are classified into 5 types of colors as per each grade, and the computed risk levels for each activity can be visually checked. Therefore, it is possible to intensely manage those works with high risk levels.
Fig. 3. Workspace conflict optimization module by genetic algorithm

Development of the Active BIM Functions for the Construction Management

Workspace conflict optimization module

Fig. 3 shows the developed 4D simulation screens that simulate the minimization of workspace conflicts based on the GA-based workspace conflict optimization methodology. The left figure in Fig. 3 shows a workspace conflict simulation model before optimizing schedule overlapping status. Conflict (1) and (2) for base workspace was occurred based on planned schedule. While, the right figure in Fig. 3 represents a workspace simulation model after optimizing schedule conflict with GA approach. Compared to the former model, it is recognized that the workspace conflict is occurred only in conflict (1) for base workspace.

A workspace conflict optimization analysis verifies an element model for WBS and each interface activity with the planned 4D model and creates a required workspace. Then, schedule conflicts and workspace conflict are simultaneously analyzed in order to search for those activities with both conflicts. For the search of workspace conflicts, those activities with schedule conflicts are analyzed by checking the workspace adjacency distances between overlapping schedules. If the analysis results go through 4D simulation, the corresponding schedule conflicts and workspace conflicts can be visually checked over the period of time.

Since these simulation results are based on 4D modeling of the planned schedules, an improved optimization 4D model that minimizes workspace conflicts should be created. By minimizing the overlapping of the workspace-interfaced schedules, a combination of optimal schedules that minimizes the total conflict ratio can be searched. Hence, the 4D simulation results that resolved workspace conflicts can be derived as shown in the right screen of the Fig. 3.

Development of a system that is interface with risk assessment module

Fig. 4 shows the developed 4D simulation screens that quantify a project’s risk factors and convert them into visual data. The left screen of Fig. 4 shows the results of risk assessment by Fuzzy-AHP approach. We can identify risk degree on how much level each activity has for risk factors with color-coded property. The right screen of Fig. 4 represents the 4D simulation model of risk factors for each element model.

Items for risk analysis should be first selected through WBS, and analysis priority values for a project’s risk factors such as project period, costs and work conditions should be defined. Then, particular linguistic variables for each activity’s risk probability and impact are registered by a construction manager. Once the risk analysis is executed, each activity’s risk levels are depicted in colors as per an embedded fuzzy analysis algorithm. If these risk levels are updated into a 4D model, then the right screen of the Fig. 4 will be displayed, which shows the risk levels in color-attribute values. Therefore, risk levels for all

Fig. 4. Risk visualization module by fuzzy algorithm
activities as per a project’s progress can be visually provided through 4D simulation. This will allow workers to selectively sort out those activities with higher risk levels and generate a report. That is, optimal risk assessment can be attained.

CONCLUSION
This study has developed an active BIM methodology and system that improves the passive BIM system in order to provide an integrated workflow during the construction phase. To do this, this study has developed a module that could optimize such project management data as schedule conflict and workspace conflict, and also a module that could assess those risks associated with construction works. These modules were integrated through a 4D CAD system that was developed in the study. With all these modules and systems, this study could verify that active BIM functions providing such schedule management data that are optimized for each project could be developed from current BIM functions that are focused on the simple visualization. It is expected that all these advanced functions would be used as basic data for the establishment of active BIM environments.

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References
Advanced Process Control for Infrastructure Building Processes

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Purpose In this research, novel information integration technology and advances in wireless communication, positioning and machine control systems were combined into a general control method for an improved multi-contractor infrastructure building process. More intense competition and new environmental regulations in the field of infrastructure building are forcing companies to revise and intensify their processes. There is a clear need for tools enabling more efficient process management. In this research, the objective was to find out how to improve process management through more efficient information exploitation.

Method We conducted a literature review and interviews with professionals in the field to find out requirements for improvements in process management.

Results & Discussion Based on the requirements revealed by the literature and interviews, the developed control method exploits common ontology models to integrate design and construction time process data with the help of advanced communication, positioning, and machine control applications. In addition to construction time process control, the utilization of the developed control method also potentially intensifies operations before and after the project. The developed method for example makes offer requesting, project control and maintenance potentially more efficient and therefore makes processes safer, more cost-efficient, eco-efficient, and greatly helps the product data management. The development of the method is the first step and the results will be verified in a next research phase by practical implementation.

Keywords: infrastructure building, information integration, semantic methods

INTRODUCTION
The infrastructure building companies among the other industry nowadays are facing a huge pressure to strengthen and intensify all the processes due to hard competition, the new regulations and public demand for more pro-environmental processes. Talking about the large scale infrastructure building projects they are less organized and formalized due to more badly measured process parameters, lower technical status of factors of the process and sometimes quite complicated subcontractor chains. The technology variety and technology knowledge of different subcontractors in the same site cause difficulties to project and process control. Infrastructure project consists several parallel processes where machine break down or other kind of interruption can cause delays and unplanned costs. A random interruption in the process including several parallel sub-processes may cause problems in large scale. These interruptions should be handled immediately preferable automatically as fast as possible. However, in many cases in the infrastructure building, process data is handled slowly and manually by error-prone human operators without knowledge from every affecting process parameter. The implication of the aforementioned example is that in infrastructure building process, control is difficult. Difficulties in control leads to the situations where the status of the sub-processes are worse known, making the overall process control and dynamic reaction to the changes impossible and therefore processes are more inefficient, hazardous, expensive and slower.

According the description above, there is a clear need in the infrastructure building industry for the deployment of more intelligent process control methods concerning both the information of the original plan and the dynamically changing construction time process parameters. The research problem was to develop suitable control method to answer the need. The developed method allows integration of the most important subcontractor process information to be used by main project coordinator for more efficient process control and reaction to the changes in the field. The main benefits of the method are more efficient, cost-effective, more environmental friendly and safer infrastructure building projects through the improved production data management. The most important facilitators of the control method are novel technologies in the areas of the machine control systems, data formats, location systems, information management technologies and finally general Web technologies.

In this study, a novel method for the improved process control was developed. In the method, the management of the design data, automatic dynamically changing and manually added process data is formalised in a way that it could be easily integrated as
a whole and where the information format provides also means to successfully do automated data fetching and inferring.

**State-of-the-art**

Commercial state-of-the-art products of construction project management offers proper tools for data storage, data analyze and instant messaging, but components for open, vendor-independent data integration tools are missing. In the academia, the infrastructure building topics are also vastly researched. In mid-1990’s Navon et al. begun to research construction industry management. Industry related state-of-the-art research has been conducted in Israel. Navon and his colleagues focused in their researches on automated productivity measurements using GPS-data and the concept of work envelopes. In the same time Navon state that in the beginning of 2000 century the background for the construction process control was thin and all the actions were done by manually made calculations.

Later on two German research projects has started to study the ways to improve construction processes and management. Researched focus areas were e.g. improving the total construction process and optimizing the workflow with the help of machine control, logistics planning, virtual phase visualization, documentation and data management. State-of-the-art technology like PDM-systems and close range identification were used to help reaching the targets. Several academic researchers have also researched lately the potentials of ICT-related construction management. The common factor of these ICT-related researched mentioned above is the use of novel ICT technology for process measurement and follow-up.

A method for information integration in infrastructure building was developed by El-Diraby et al. in few related studies. In these studies, semantic methods are used to formalize information as well as relations between those information instances. The study, presented in this paper exploits some of the main ideas of these studies like creation of ontologies for different sub-processes for information formalization.

**Research methods and method enablers**

The base research method for the improved building process control that has been developed was quite straightforward. It was based on a state-of-the-art study, the contractor and their employee interviews, industry partner workshops and worksite visits. The deployed information integration method is based mainly on the semantic methods but the utilization of the method in the real world case would not be possible without new technology advances like open data formats, automated machine control systems, automated positioning systems and wireless mobile technologies.

**Technology state-of-the-art and research partner practice surveys**

The need for the novel process control method and its type were researched in several different ways. In the beginning the state-of-the-art survey were done for developed similar systems among the commercial products and academy researches to verify the need and to find already developed corresponding methods. Then the key position personnel were interviewed among the main and subcontractor companies taking part to the research project and the work site observation were done. Also two workshops among the project partners to discuss the topic were held. Finally, the potential technology enablers were studied and the most suitable were chosen to be used.

**Semantic technologies**

As a main technology for realizing the improved process control system, Semantic Web related technologies were utilized. Semantic Web is a concept for the next generation WWW in which information is given well defined meaning. The underlying technological infrastructure of Semantic Web is referred to as Semantic Technologies. Semantic technologies contain for example ontology tools, dynamic mediation tools, inference tools and thesaurus tools. Ontologies and ontology tools are in central role in information integration.

In information integration the semantics of information is preserved while the context is transformed. Semantic technologies, especially the usage of ontologies, offer a way towards solving the information integration challenge. Ontology captures consensual knowledge in a generic way to be reused and shared across software applications and by groups of people.

In ontology based model the semantics of information is modeled as classes and relations between those classes. The W3C’s Semantic Web activity has developed many related technologies such as Resource Description Framework (RDF), RDF Schema (RDFS), Web Ontology Language (OWL), and SPARQL to realize the ontology based interoperability in the WWW. In this research, all the process data from the design to the real-time process data is stored to the triplet database to be easily deployed with the help of inferring when needed.

**Open design data formats**

New open design data formats for the building processes make it possible to reuse design data in different CAD and other applications. These new data formats are in many case well documented and XML-formatted making it even easier to be exploited in general. The developed process control method ex-
exploits one of the lately developed formats called InfraModel2 that is based on LandXML specification and targets i.e. road, street and water route design\textsuperscript{18}. XSLT transformation were used to convert the design file to RDF type ontology.

**Automated machine control systems**

The recent commercial machine control systems have opened a completely new era in the some of the sub-processes in the infrastructure building. With help of the wireless communication technologies, machines can now receive work instructions and send up-to-date process data on-demand enabling better real-time process control on their behalf.

**Wireless mobile technologies**

Realization of the control method described in this study would not possible without the novel wireless mobile communication technologies like wireless operator networks. The requirement to transfer larger amounts of data wirelessly more frequently is clear if the greater level of real-time behavior is wanted. Although the needed data transfer will be small if only machine guidance, survey, status and mass transfer related data is transferred.

### RESULTS

**Method requirements**

In addition to the state-of-the-art review and field study observations, personnel of the involved project partners were interviewed to get a better idea of the process control method requirements. The interviews of the study covered personnel basically from each sectors of typical actors from large scale infrastructure building project. Among the interviewed key personnel there were representatives from a builder, a designer, main contractor as well as subcontractor system supplier companies. Subcontractor system supplier companies covered a design tool provider, a mass transportation management system provider, a machine control system provider and road measurement system as well as end users of those systems.

Amount of the interviewed personnel were only about 2 persons per company type, except the main contractor where around 5 persons were interviewed. Since the amount of the interviewed persons was quite few, the interview results are not all-covering, merely giving a basic idea of the system requirements. Sub-topics of the interviews covered partner’s recent official practices concerning project-wide and inter-partner information flow, future plans and interviewee’s own opinion of the way practices should be realized. The interviews and the questions were tailored according the interviewee type. The answers included direct suggestions how to improve practices as well as indirect observations that were translated to requirements by authors. E.g. one of the answers of the main contractor explained what the most important observed process parameters are and what the preferred update interval for them is. The interview results completed the information received from worksite observations, a partner workshop, the state-of-the-art review and the authors’ experience from the other related projects. The requirements of the system contain both the exploitation possibilities of the information and the overall integration system requirements. The most important requirements for the intended control system are listed in Table 1. The list reveals that an efficient control system for the purpose includes at least some of the following features: soft real-time, decentralization, system independence pre-agreed subcomponent interfaces and decision-making capabilities. State-of-the-art survey revealed us that there is general purpose information integration method developed in academia suitable for the infrastructure building processes\textsuperscript{12}. However, there was no such a case found where the general information integration method was used for construction time process control purposes. There are also many different examples how different sub-processes or special focused needs could be covered, but none of really matching the needs mentioned above.

![Table 1](https://example.com/table1.png)

<table>
<thead>
<tr>
<th>Need</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi real-time</td>
<td>Response time should be within tens of seconds.</td>
</tr>
<tr>
<td>Easy system integration of different actors needed without custom programming</td>
<td>Common data models for both design and run-time process data provider parties are needed.</td>
</tr>
<tr>
<td>Automated decision making</td>
<td>Data formats supporting machine based inferring.</td>
</tr>
<tr>
<td>Non-system dependent</td>
<td>Using information management system should be done using common platform independent technologies.</td>
</tr>
<tr>
<td>Possibility for decentralized system</td>
<td>No need for Common repository for process data.</td>
</tr>
<tr>
<td>Selected site parameter monitoring</td>
<td>Necessary function of the concept, concerning proper site progress monitoring.</td>
</tr>
</tbody>
</table>

**Method description**

The process control method presented is based on the described requirements. As we have studied in earlier chapters, one of the most important matters in order to realize an advanced process control system seems to be general data interoperability that can be realized e.g. with pre-agreed common data formats that enables ease assembling of smaller portions of data to usable wholeness. Those data formats should also be machine understandable. Also important properties of the control system are system inde-
pendency and possibility to realize system with de-
centralized architecture. The main idea of the devel-
oped method is to develop and use common ontology
type that contains sub-ontology for each subcon-
tractor type of the infrastructure building process. For
example there should be different sub-ontologies for
the design and different process data providers like
mass transport or excavating companies. Sub-
ontologies contain only relevant data instances and
their interrelations. Figure 1 illustrates a simple snip-
et of subcontractor resource ontology model.

The common ontology guarantees the information
interoperability and possibility to do inferring based
on the data relations. Using the developed method,
all the ontologies were described in OWL format to
enable easy ontology combination from the different
fragments.

Method utilization prerequisites
In order to realize an efficient process control meth-
ods based on system requirements described in pre-
vious chapter, there are some initial prerequisites to
be fulfilled. These prerequisites should be taken into
consideration in the very early phase of agreement
concluding between the project participating compa-
nies. The most important prerequisites are explained
in Figure 2 and Table 2. These prerequisites are
needed since at present there are no standard on-
tology templates for different actor types.

System architecture
In the developed method, the main contractor is the
party that is coordinating data collection and reuse.
Both decentralized and centralized methods can be
used. In decentralized method, all the other partici-
ating companies just give the main contractor an
access to their remote information repository contain-
ing generated process data in OWL format and the
main contractor fetches data from there and com-
bines them when necessary. In our study however,
the centralized method is the one that is in the focus.
In the centralized method, all the parties send their
design and process data in correct format to the
server provided by the main contractor in agreed
intervals and the main contractor takes care of the
data exploitation and its possible distribution and
reuse. Figure 3 shows a simplified architecture and
the data transfer principles of the centralized version
of the developed information integration method.
Designers deliver design related information, like
construction and schedule design, to main contrac-
tor’s server as well as information about any changes
made to the design information during the project.
Subcontractors transfer process related data to the
main contractor’s server; this information may contain
e.g. excavation status and mass transfer data with
related machine location data. Subcontractors are
able to receive realization information about project and for example work instructions through information system. Main contractor adds its own process related data, which is combined to subcontractors’ data. The developed system offers the integrated information to main contractor through information integration system’s user interfaces. All the data transferred to main contractor’s server is formatted according to agreed ontology model. The ontology is realized using OWL.

**Fig. 3. The control system architecture**

**Illustrative Use Case**

An illustrative use case describes the planned use of the new control method concept. Use case is divided into three parts and it considers three actor types (designer, main contractor and sub-contractors). First phase of the use case is initial state and the following phases are operational. Presented use case is ideal and heavily simplified. Use case presents the use of the control method in a road construction case. The use case will be implemented for real-life implementation in the next phase of this research.

**Initial state**

In the initial state all needed road designs, machine guidance models, mass hauling plans and schedules are uploaded into the server following the researched prerequisites, see Table 2. Initial state models, plans and schedules have designed by group of designers and verified by construction site operating officer.

**Execution**

Execution phase is divided into two parts; cut-and-fill and mass hauling. Therefore execution phase considers only two actor types (excavator and truck). Excavator is equipped with state-of-the-art machine guidance system with wireless data transfer technology. Cut-and-fill is done by instructions from a machine guidance model. Mass hauling trucks record every load they transport using a mobile application. Recorded mass hauling data is sent in real time to the server, where it has been compared to plan. In the execution phase main contractor can monitor and control the execution task progress by comparing the schedules and realization models since they are part of the same common ontology model. Progress is presented graphically enabling easy project status observation. If realization seems too fast or slow the supervisor can react accordingly.

**Quality assurance and task approving**

In a quality assurance and task approving phases the executed work is recorded by machine guidance and mass hauling systems and results are delivered to the server as an as-build model. After comparing the as-designed and as-built models the main contractor can approve the task and give the permission to start the next phase of the construction.

**DISCUSSION**

The driving factor of our research was the lack of proper general tool for project management concerning the site officer, who is in charge of daily construction actions. The general process control method was developed for that purpose. Utilization of the developed control method could also affect in many different sub-topics in the infrastructure building sector as well as to other domains with scattered contractor chains and not formalized production methods. The gained benefit comes due to formalized, easily combined data formats ensuring the better interoperability and enabled automatic inferring and decision-making based on the collected data. The design data could be used more effectively when it is used as an initial data to be compared to the realization data which improves process follow-up. Also the collected process data is easier to integrate in order to enhance the process monitoring, quality control, faster reaction, safer and more efficient processes and after the project for maintenance focusing and improvement. The collected data could also be used after the project as a reference for a more efficient offer requesting processes and descriptions. The semantic way to present project data with internal relations eases also the exploitation of novel PDM-systems.

The developed method is quite scalable, general purpose and easily deployable. Each company taking part to a construction project could use their best known software technology and platform and take part to information chain. The developed method is also usable in other related tasks e.g. invoicing process as for example the realization of a certain mass hauling task may be allocated to certain a subcontractor. This reduces need of human work in invoicing as it reduces paper handling. This also gives better opportunities to main contractor to order extra
machines for example for mass hauling. During development of the information integration method also maintenance after construction was taken into account.

Previous and currently running research projects have been studied. Methods how to monitor and manage processes and how to gather liable status information from the infrastructure building projects were researched. In many cases automated data gathering and GNSS-positioning systems are the main factors of the developed concepts, but the way how this gathered data is analyzed and used again varies between different projects. Nowadays the common way is to develop an algorithm that monitors automatically where the assets are moving and realizes which part of process is in progress. The control method developed in this research exploits also GNSS-positioning and other novel ICT technology, but the main focus is in the ontology based information formalization and its utilization for information integration purposes. Several lately conducted researches have same kind of integration approach where enterprise level systems and software’s are integrated to concept database. Developed methods have also same key features like web-based platforms, databases and mobile accessories which are noteworthy technologies because the latest developments in wireless network and other ICT-related areas. There are also examples where ontologies are used for information integration purposes in the field of infrastructure building processes. These examples however did not point out how to use them to the process control purposes and neither there were explanation what kind of extra prerequisites were needed to fulfill to really deploy them.

During research process couples of drawbacks were recognized. Since the infrastructure building process is quite scattered concerning to level of the used technology among the subcontractors there will be problems to add all the needed parties to the system in practice. Also the utilization of the semantic methods demands high technology orientation from the using party with the skilled personnel before the routines to use the method evolves. Due to quite heavy data formats and system structure the method does not allow hard real-time utilization. Of course the possible production system using the developed method would demand heavy standardization process for development of real common ontology. One drawback is also the lack of clear earning principles. Of course, if the benefits are high enough for the main parties, the demand for method from the main builder side would speed up the process. At the moment the current sub-contractor software data formats do not support ontologies described in this research, causing an issue demanding data format converter or specific interface for every subcontractor counterpart.

As pointed out the need for additional research is clear. Since there is already few main example ontologies developed, the proof-of-concept implementation system should be done including the integration of the design data, scheduling data and some important process data. Also a tool improving the construction time process management with user interface should be included. The implementation should be tested concerning the performance and utilization experiences from real users. Also the business model to motivate additional funding for research should be clearly pointed out.

ACKNOWLEDGMENT

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Markerless vision-based Augmented Reality for enhanced project visualization

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Purpose This work aims to develop a system that enables improved visualization of Architectural Engineering and Construction (AEC) 3D-information for application in design, construction, and management of the built environment. Method A novel Augmented Reality (AR) system is presented that uses a single standard digital camera and which, contrary to other investigated approaches, does not rely on any markers inserted in the scene, nor on any positioning and inertial technologies. The system is solely image-based and consists of two stages. In a first offline stage, a 3D-map of the scene is automatically constructed from a set of digital images, and the augmenting information (e.g. the 3D-model of the building asset) is subsequently registered with this map. The 3D-map reconstruction employs structure-from-motion techniques with SURF features (the resulting map consisting of a set 3D-referenced SURF-features) followed by a Poisson mesh reconstruction procedure. The next step consists of online operations. The positions of target digital images (e.g. from video stream or head-mounted camera) are automatically calculated, using a robust SURF feature matching procedure that is optimized for three different situations (initialization, tracking, and resetting) implementing octrees for efficient 3D-pruning, and kd-trees for efficient feature matching. Once each input image is positioned within the map, the view is augmented. A notable feature of dense mesh scene reconstruction conducted in the present work is that it enables static occlusions of the scene on the augmenting data to be taken into account. Results & Discussion Several experiments validate the proposed system and demonstrate its overall performance: a near real-time processing speed, very accurate and stable positioning. The limitations of the current system are also discussed including: the currently limited processing speed and the need for adequately textured scenes.

Keywords: realities or application systems, augmented reality, image-based, markerless

INTRODUCTION
Visualization in Construction
Construction projects are complex endeavors requiring the collaborative work of numerous different stakeholders, and generating large amounts of data and information from which complex decisions are made. Thanks to exponentially increasing computational capabilities, Building Information Modeling (BIM) is now being intensively developed with the aim of more efficiently and effectively managing lifecycle construction information. Rooted from 3D modeling and visualizations, BIM engines offer enhanced visualization and management of construction information. Virtual Reality (VR) immersive environments are further proposed in order to enhance user experience in navigating the created virtual worlds. Numerous works have been published with regards to the development of VR environments but in these systems the visualization remains entirely within a virtual world. It is noted though that some technologies are being developed to capture the state of actual construction projects and integrate it within the project Building Information Model, but the virtual information may need to be more closely linked and visualized with the real world. It is noted though that some technologies are being developed to capture the state of actual construction projects and integrate it within the project Building Information Model, but in these systems the visualization remains entirely within a virtual world.

2. Single-user. Many VR environments, i.e. VR Immersive rooms, focus on single user experience (only one “view” of the model can be seen at a time), preventing multiple users to simultaneously have their own views of the information. Nonetheless, we note that some more complex systems are being developed that enable multiple views simultaneously.

Augmented Reality
On the other end of the virtual continuum is Aug-
mented Reality (AR). AR aims at fusing virtual and actual information, e.g. by projecting virtual information on head-mounted displays (HMDs) that simultaneously enable the visualization of the real environment around. As a result, AR inherently has the potential to overcome the two main limitations identified above.

AR has already been investigated for application within the AEC industry with systems such as ARVISCOPE\textsuperscript{8} and AR4BC\textsuperscript{9}. These systems demonstrate the great potential identified above, but they also exemplify the challenges faced in developing such systems:

1. **Positioning**: In order to ensure a realistic and accurate overlaying of the virtual information on the viewed real world, the positions with regard to the real world of both the virtual information and the person (e.g. HMDs) must be known very accurately. In AR, small errors in those estimations rapidly result in obvious errors in the overlay. Regarding the AR systems reviewed above, it appears that, although systems based on positioning technologies like GPS and inertial sensors have the advantage not to require any prior knowledge of the scenes, they are fairly unstable due to the sensors inaccuracies.

2. **Occlusions**: Unless 3D information about the actual real world is available, occlusions of virtual objects by real-world objects are often not taken into account, resulting in obvious artifacts (ARVISCOPE\textsuperscript{8} suggests the use of range camera to compute such occlusions in real-time, but these cameras only work for ranges lower than 10m).

This paper presents a novel AR system that is based on different technologies as those traditionally investigated. The main particularity of the system is that it does not rely on any beacon-based localization (e.g. GPS) or inertial navigation systems (although they could all be used complementarily). The system is solely image-based. This is achieved at the cost of a prior visit of the site of interest where numerous digital pictures must be acquired. The images are used by the positioning algorithm, but have the secondary advantage that they can be used to reconstruct a 3D model of the site, that can be used to compute static occlusions of the site on the augmenting information, an advantage over previous approaches.

**SYSTEM OVERVIEW**

The system is composed of two stages. In an **off-line mapping** stage, the actual 3D scene is first learnt and then augmented with virtual elements. Subsequently during **on-line** operations, for each image of the input stream (**target images**), the camera pose is first estimated, and the image is then augmented with appropriately occluded virtual scene objects. These two stages are detailed in the following two sections. Then, validation experiments are presented that demonstrate the performance of the system.

**OFF-LINE MAPPING**

The offline mapping process is composed of two sub-stages detailed below: (1) learning the scene; (2) augmenting the scene.

**Learning the scene**

The input to the learning stage includes a set of images of the scene of interest, called **training images**, with corresponding camera intrinsic parameters. The mapping process, summarized in Fig.1, is fully automated and goes as follows. First, **Speeded Up Robust Features (SURF)**\textsuperscript{10} are extracted from all training images. These SURF features are used in a **Structure-from-Motion (SfM)** framework to recover the scene 3D structure. SURF features are used in an initial sparse matching step to select candidate image triplets for projective reconstruction. The robustness of SURF features to scale changes allows some constraints about camera motion to be relaxed (normally constrained to turn around the building to be reconstructed), permitting camera paths at different distances from the building. A subsequent robust Euclidean **Bundle Adjustment** from candidate views directly registers the 2D SURF descriptors in the reconstructed Euclidean 3D reference frame to build the map of 3D-referenced features. This approach effectively populates the map with 3D-referenced SURF features. We use the ARC3D framework\textsuperscript{11} for 3D scene mapping and self-calibration.

This paper presents a novel AR system that is based on different technologies as those traditionally investigated. The main particularity of the system is that it does not rely on any beacon-based localization (e.g. GPS) or inertial navigation systems (although they could all be used complementarily). The system is solely image-based. This is achieved at the cost of a prior visit of the site of interest where numerous digital pictures must be acquired. The images are used by the positioning algorithm, but have the secondary advantage that they can be used to reconstruct a 3D model of the site, that can be used to compute static occlusions of the site on the augmenting information, an advantage over previous approaches.

**Augmenting the scene**

ARC3D actually provides us with an additional feature that is of particular interest to our system. In addition to learning a 3D map of SURF features, ARC3D enables a dense reconstruction of the acquired scene, in the form of a 3D (textured) mesh, using the same input images (we use Poisson mesh reconstruction for this). Compared to the point cloud
of the reconstructed map, this mesh presents two advantages:
1. It simplifies the manual insertion of virtual objects in the scene (discussed below).
2. During online processing, it enables the computation of occlusions by the scene of the virtual objects and vice versa.

Given the dense 3D mesh of the scene, the user can easily insert virtual (augmenting) 3D objects within the scene. Note that, in the case when a virtual object is planned to replace an existing one (e.g. a building planned to be demolished and replaced by a new one), the user just has to remove from the reconstructed mesh the parts corresponding to the objects to be replaced. This ensures that occlusions caused by the objects to be replaced are not taken into account when augmenting the target images with the new objects.

Experiment shows an example of a reconstructed scene augmented with a virtual building.

ON-LINE IMAGE STREAM PROCESSING

Image Positioning

During on-line operations, the system processes the target image sequence (e.g. from a video stream). For each target image, SURF features are extracted and the $S_{\text{target}} (=1500)$ strongest ones are matched with the SURF descriptors in the database (using the Euclidean distance in a 64-dimensional space). Matched feature descriptors permit to establish correspondences, called matched 3D points, between the 2D image coordinates of the target image features and the 3D coordinates associated to the matched map features. Knowing the target camera intrinsic parameters, the camera pose is then estimated from these correspondences by wrapping the 3-point algorithm in a Random Sampling And Consensus (RANSAC) framework — i.e. triplets of feature matches are iteratively tested in 3D to find the one that leads to the most matches being geometrically correct. The resulting initial pose estimation is subsequently used in a Guided Refinement process, in which the database 3D points culled using the frustum from the initial pose estimate are reprojected on the image plane of the target image, and matches to the target image SURF features are identified only within a radius of $\rho_{2D}$ pixels (in our implementation, $55\rho_{2D}=15$ pixels). This process enables to reassess all initial matches and identify additional ones. Finally, a refined pose estimation is obtained by putting all matches into a Levenberg-Marquardt non-linear pose optimization algorithm.

Image Positioning Optimization

While the method above can enable robust pose estimations, it would require a brute force matching of the target image features with all features in the learnt scene map. In other words, its complexity is proportional to the size of the scene map, i.e. database of 3D-referenced SURF descriptors, which would prevent real-time applications. To avoid latency in the system, we implement different techniques to expedite matching without jeopardizing the quality of the pose estimates. These are presented in the following subsections.

K-d tree of scene database features

We use the common strategy consisting of partitioning the SURF descriptor space into a k-d tree, so that, when matching each target image feature descriptor, only the subspace associated with the target descriptor is visited. This effectively reduces the computational payload.

Filtering scene database features by strength

SURF features can be given a value of reliability, or strength, which is associated to the Hessian response. Strength depends on the scene feature, the viewpoint and the lighting condition of the image, thus capturing the repeatability of the feature. However, this repeatability measure is specific to the image from which each feature is extracted, while each scene database 3D points is calculated from the matching of features extracted from different images. In order to obtain a global SURF strength, we thus propose to assign to each 3D reconstructed point the average of the strengths of the SURF features corresponding to that point in the different input images. This way, SURF descriptors can be globally sorted and only those with a high average repeatability can be retained. Of course, more sophisticated weighting algorithms of the different strengths could be implemented.

Multiple Matching

Due to the repetitions and self-similarities often observed in urban architecture, there is a high likelihood that any target image feature be matched with high confidence with several database features. Enabling matching with the best matched feature only would create the risk of wrong matches and consequently wrong pose estimations (mathematically right, but actually wrong). It is thus proposed to enable one-to-many matches between each target image feature and the database features. Correct poses are then identified through the RANSAC-based pose estimation framework.

Additional heuristics are proposed to increase matching performance depending on the three configurations, or modes, that can be encountered during the processing of the stream of target images: (1) Pose initialization; (2) Pose tracking; and (3) Pose resetting. These three modes are further described below. Fig. 2 summarizes the strategy used during on-line processing to position each target image.
within the learnt 3D map.

Pose initialization

Pose initialization is the mode when no prior knowledge about the pose of the camera is available, e.g. at the beginning of the processing of the image stream, or when tracking has failed for \( n \) consecutive images (we use \( n=20 \)).

In this situation, matching must be made considering a set of database features well spread within the entire scene. To achieve this, we arrange the 3D-referenced feature points into an octree, where each node represents a partition (cuboid) of the 3D scene. The octree is populated with all scene 3D points, splitting each node once the number of points it contains reaches a threshold \( N'_{\text{max}} \).

While the full octree is used in the other two modes described below, during pose initialization, a pruned octree is used to speed up matching. The pruned octree is constructed by removing all octree cells with a volume smaller than \( V_{\text{min}} \). The points within those cells are combined in the parent cell (with volume larger than \( V_{\text{min}} \)) and only the \( N_{\text{max}} \) points with the largest global SURF strengths are retained. The resulting pruned octree contains much fewer points that the entire one, but these cover the entire scene as homogeneously as possible. In our implementation, we use \( N_{\text{max}} = 200 \) and \( N'_{\text{max}} = 400 \) and \( V_{\text{min}} = 5\text{m}^3 \). Note that the pruned octree is only computed once offline.

Pose tracking

In this mode, some knowledge about previous camera poses is available. Assuming linear camera dynamics, a prediction of the pose of the current camera is made using an Extended Kalman Filter (EKF)\(^{16} \). The frustum of the predicted camera pose is then used to cull the full octree (near and far culling planes are used with distances set to 0m and 50m respectively). Furthermore, only the \( S_{\text{frustum}} \) strongest features of the points located in the predicted view are considered for matching and are organized in a k-d tree. In the experiments presented below, we use \( S_{\text{frustum}}=S_{\text{target}} \).

To prevent the system from considering unreasonable pose predictions, we reject any prediction with a change in camera orientation larger than \( \frac{\pi}{180} = 0.1\text{rad} \) (\( \approx 5\text{deg} \)), in which case the camera pose is computed in Reset mode (see below).

Pose resetting

In this mode, tracking has failed for the given image, but was successful for at least one of the last \( n \) target images (see Initialization mode). Given the location of the last successfully calculated pose, we then cull the full octree using a sphere centered at that location and with a radius of \( \rho_{\text{sphere}}=50\text{m} \). Additionally, like in Tracking mode, only the \( S_{\text{sphere}} \) points with the strongest global SURF strengths are kept for matching and are organized in a k-d tree. In the experiments presented below, we use \( S_{\text{sphere}}=4S_{\text{frustum}} \).
Augmenting Stage
Once the system has confidently calculated the pose of the camera corresponding to a target image, this image is augmented. In order for this augmentation to take occlusions from the reconstructed 3D scene into account, the simple procedure shown in Fig. 3 is used, that simply aims to reproject on the target images the parts of the augmenting object(s) that are not occluded by the reconstructed 3D scene mesh.

VALIDATION EXPERIMENTS
The proposed AR system has been tested using several different urban scenes, with different levels of complexity with regard to the amount of texture, as well as the repetition of textures (which can confuse the system). Two experiments are presented here. The first is detailed, and aims to highlight the overall performance of the system. The second experiment demonstrates the performance of the system in a very different context. The attached video illustrates (1) the detailed stages and results achieved in the first experiment, and (2) the results achieved in the second experiment.

Experiment 1: Housing Estate in Edinburgh
This experiment was conducted in a modern housing estate composed of apartment buildings and located in Edinburgh, Scotland. 22 training images of a part of the estate were taken by a person walking around it. The pictures have a 2048x1536 resolution, i.e. ~3M pixels (see attached video). The processing of the images results in two files, containing the list of 3D-referenced SURF features and a 3D mesh of the scene, which is then augmented with an additional building (see Fig. 4). A set of target images was acquired later. The same digital camera was used with the same initial resolution (2048x1536). In order to simulate a video sequence, 120 images were acquired in ‘burst mode’.

Fig. 5 shows the results obtained for some of the input target images with resolution 2048x1536. A visual analysis of all the results (see attached video as well) for all target images shows that all poses were successfully calculated. Nonetheless, it is noted that at four occasions when a target image was processed in tracking mode, a sharp acceleration in the camera orientation occurred and the EKF prediction resulted in a change of camera orientation, \( \delta \), slightly larger than \( \delta_{max} \). This resulted in the estimated pose being rejected by the system and recalculated (successfully) in Reset mode. The reason for these rejections is that the low-frequency of the data acquisition in ‘burst mode’ (~1fps) made possible significant camera motions between frames. Even then, the system achieves accurate pose estimations and effectively recovers from tracking failures.

Tab. 1, 2 and 3 present pose estimation performance results obtained using the dataset with all images having 2048x1536 resolutions. The three tables report results for experiments conducted with and without two options: Multiple Matches (MM) and Guided Refinement (GR). Tab. 1 reports the average numbers of features used for matching and the average numbers of matches obtained (for the three possible modes). Tab. 2 reports the success rate in pose calculation, based on the software’s own assessment criteria. Finally, Tab. 3 reports the average processing times obtained for the different modes. The analysis of these results shows that, as ex-
pected, MM and GR tend to improve the success rate in pose calculation. However, in this experiment at least, the improvement is not critical, since it does not significantly improve the pose estimation success rates (a visual analysis of the results shows that, in that particular experiment, the software actually achieves 100% in all cases.). Then, Tab. 3 shows that the use of GR significantly impacts the average processing time with an average increase of \( \sim 40\% \), and that the current implementation of the proposed tracking system does not enable processing speeds that would support real-time applications. The issue of processing speed is investigated further below.

Tab. 4 compares the performance achieved by the system for training and target images with different resolutions, after visually controlling the results. Clearly, the system performs best when the training and target images have a similar size. While this is generally not surprising, it also shows that the scale-invariance property of SURF features can be put to the limit if the difference in image resolution is significant (given that the scene is observed from similar distances). These results also tend to show that small images actually achieve similar pose estimation performance as large images, with the advantage of faster processing times (see Tab. 5).

Tab. 5 presents computational times similarly to those in Tab. 3 but for training and target images with resolution 640x480. It appears that, although the number of image pixels is effectively reduced by a factor of 10, the computational efficiency does not improve that significantly. This is due to the fact that, although the computation of the SURF features for the target image is significantly sped up, the parameters \( S_{\text{target}}, S_{\text{frustum}} \) and \( S_{\text{sphere}} \) remain unchanged, so that the system calculates a similar number of matches.

Tab. 6 presents computational times achieved with training and target images with resolution 640x480, and the parameters \( S_{\text{target}}, S_{\text{frustum}} \) and \( S_{\text{sphere}} \) set to \( S_{\text{target}} = S_{\text{frustum}} = 500 \) and \( S_{\text{sphere}} = 2,000 \). The pose estimation quality are not impacted by these settings, but the processing times are further decreased (although not that significantly).

Fig. 5. Experiment 1 - Eight of the 120 target image stream before (lines 1 and 3) and after being augmented (lines 2 and 4)

Tab. 1. Experiment 1 - Statistics of the pose calculation performance for the three modes Initialization, Tracking and Reset. The columns Matching and GR report the results obtained after the initial matching stage and the guided refinement stage respectively. The columns DB and Match report the number of map features used for matching and the number of matches found.

| MM | GR | Initialization | | Tracking | | Reset |
|----|----|---------------||-----------||-----------|
|    |    | Matching | Match | DB | Match | DB | Match | DB | Match | DB | Match |
| No | No | 2,675   | 114   | N/A | N/A   |   |   |   |   |   |   |
| No | Yes| 2,675   | 114   | 1,500 | 232  |   |   |   |   |   |   |
| Yes| No | 2,675   | 119   | N/A | N/A   |   |   |   |   |   |   |
| Yes| Yes| 2,675   | 119   | 1,500 | 286  |   |   |   |   |   |   |
Tab. 2. Experiment 1 - Statistics of the pose calculation performance, as reported by the system. In brackets are the numbers of images processed in the particular mode.

<table>
<thead>
<tr>
<th>MM</th>
<th>GR</th>
<th>Success rate (system)</th>
<th>Initial.</th>
<th>Tracking</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>100% (1)</td>
<td>95% (124)</td>
<td>100% (6)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>100% (1)</td>
<td>97% (124)</td>
<td>100% (4)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>100% (1)</td>
<td>97% (124)</td>
<td>100% (4)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>100% (1)</td>
<td>98% (124)</td>
<td>100% (3)</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 3. Experiment 1 - Average computation times for pose calculation using training and target images having all 2048x1536 resolution.

<table>
<thead>
<tr>
<th>MM</th>
<th>GR</th>
<th>Mean processing time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>1.34</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>2.00</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>1.37</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>1.99</td>
</tr>
</tbody>
</table>

Tab. 4. Experiment 1 - Comparison of the pose estimation performance for different combinations of sizes of the training and target images. Small (S) images have 640x480 resolution, and large (L) images have 2048x1536 resolution.

<table>
<thead>
<tr>
<th>Image size</th>
<th>MM</th>
<th>GR</th>
<th>Success rate (visual)</th>
<th>Initial.</th>
<th>Tracking</th>
<th>Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train.</td>
<td>Target</td>
<td>S</td>
<td>S</td>
<td>No</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>S</td>
<td>No</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>100%</td>
<td>88%</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>100%</td>
<td>85%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>S</td>
<td>No</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>100%</td>
<td>94%</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>100%</td>
<td>94%</td>
<td>89%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>L</td>
<td>No</td>
<td>No</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>No</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Tab. 5. Experiment 1 - Average computational times for pose calculation using training and target images having all 640x480 resolution.

<table>
<thead>
<tr>
<th>MM</th>
<th>GR</th>
<th>Mean processing time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>0.58</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>1.25</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>1.55</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Experiment 2: Seoul Imperial Palace

The results of this experiment are shown in Fig. 6 and on the video. The experiment used 80 training images (surrounding the temple) and 90 target images (acquired in camera ‘burst mode’). All images have 2560x1920 resolutions. Fig. 6 and the video show the stability of the pose estimation algorithm of the system.

However, a limitation of the current process is illustrated in Fig. 7, which shows results for the same experiment, but with the augmenting virtual building positioned behind the temple. In that particular context the dense mesh reconstruction using the ARC3D framework didn’t achieve sufficiently good quality with numerous holes in the final mesh, so that numerous artefacts appear when computing static occlusions.

Note that this issue could be addressed by using accurate 3D urban reconstructions (e.g. GIS level 2), align them with the ARC3D reconstructions and use them instead to calculate occlusions.

![Fig.6. Experiment 2 – Six of the 90 target image stream before (lines 1 and 3) and after being augmented (lines 2 and 4).](chart)
CONCLUSION
A markerless monocular vision-based augmented reality system has been presented, with the aim of providing AEC professionals with a tool enabling them to assess project 3D digital information (e.g. BIM) within their actual environment. The performance of the system was successfully demonstrated on real imagery from two different scenes. The accuracy of the estimated poses was not directly estimated since no ground truth was available. However, the quality of the augmented images – in particular the calculation of occlusions – provides some clear observations of this accuracy. Nonetheless, improvements could be made in several areas:

- The system in its current implementation only achieves up to 3fps which is not fast enough to consider a real-time AR system. While some improvement could be achieved by varying some parameters (e.g. $S_{\text{target}}$, $S_{\text{frustum}}$, $S_{\text{sphere}}$), transferring some data processing on the GPU also seems necessary. Nonetheless, as shown in this paper, the system may already be used in an “off-line” manner by augmenting a video input.

- Compared to other commonly used approaches, our tracking strategy does not rely on tracking image features (e.g. KLT\(^{17}\)). Instead, it tracks the camera. While this approach may be more robust with respect to sharp changes in camera motion, the overall tracking is likely not as efficient. A combined system could be envisaged.

- Similarly, the current system does not rely on any global positioning or inertial system. While this brings some advantages, it also brings some limitations (e.g. GPS would be useful for initialization and resetting modes). A hybrid pose estimation module could thus be investigated.

- Since the focus of this work is on urban augmented reality, positioning techniques based on planar structures\(^{18}\) could be investigated.

- Further culling of the database features may also be achieved by considering some feature visibility criterion\(^ {19}\).

- While the system is designed to handle scenes of the size of a neighbourhood, further testing needs to be conducted using larger reconstructed scenes.

Finally, it must be emphasized that there is one limitation that is inherent to vision-based localization approaches, which is that they perform adequately only when the scene presents sufficient structure. Therefore, the current system would likely fail in the case of greenfield projects with little built environment in the surroundings.

ACKNOWLEDGEMENTS
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References


Parametric modelling based approach for efficient quantity takeoff of NATM-Tunnels

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Purpose As every construction project is quite different according to the type of construction, 3D-representations on design, estimation, construction, and management also need to be different. While the 3D-approach has been widely applied to building projects, it has rarely been tested on large construction projects such as tunnels, mass transit systems, dams, highways, etc. Meanwhile, characteristics of NATM (New Austrian Tunnelling method) tunnel projects—including long-linear-simple shapes, cyclic-repetitive operations, and relatively small numbers of objects—are compatible with parametric modeling that can be supported by BIM-applications5. The purpose of this paper is to propose an efficient approach for quantity takeoff of NATM-tunnels, using parametric modeling. Method NATM-tunnel characteristics are described that should be applied to the 3D-modeling and technical requirements for parametric modeling functions toward obtaining efficient solutions. Results & Discussion Results from a pilot project indicate that standardization on tunnel libraries, parameters, levels of detail, and parametric relationships can dramatically improve the efficiency of quantity takeoffs.

Keywords: information technology, BIM, parametric modeling, NATM tunnel

INTRODUCTION

Building information modeling (BIM) can be considered an epochal revolution in the way to design, build, share, and communicate. While meaningful BIM can be accomplished by collaborative effort of project teams from the very beginning of construction projects, current BIM environment is immature to fully support diverse demands from various project teams. BIM technologies not only have promised new opportunities to improve process in the construction industry, but have generated new challenge areas.

One of new challenge areas is to develop a well-defined library that provides automatic design ability and product information across project participants throughout the life cycle of a facility, at the aspect that library development is the most fundamental step in the BIM process. BIM utilizes a cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility throughout the life cycle of a facility4. Therefore, a BIM library as not a simple graphic representation but the most fundamental unit to compose modeling needs to involve physical and functional characteristics reflecting professional knowledge from diverse project participants. According to the building SMART Korea (bSK) report, 66% of architectural engineers describes the lack of available library and its contents as the major obstacle of BIM adoption1.

An open library system can save considerable time, effort, and cost required in the modeling process. Although free of charge online libraries are recently available through various channels, they are little useful in real practice because they might have (1) low quality or out of date data, (2) different standards, codes, level of detail or format, (3) inappropriate parametric rule, metadata, and data structure, or (4) difficulties in modification. On the other hand, a small piece of libraries requires additional effort and professional knowledge to apply the libraries one by one into modeling. Therefore a more systematic approach should be prepared in developing BIM libraries in order to facilitate BIM.

This paper proposes a new concept of development approach of BIM libraries, a holistic system library that integrates a small piece of libraries into a batch of libraries with identical parametric behaviors and product data. The new concept of development approach is useful for a prefabricated or modularized product (e.g., precast concrete, steel stair, etc.), a manufactured product (e.g., air conditioner, boiler, etc.), and a standard type of construction (e.g., standard masonry wall system, standard pavement system, etc.). This paper seeks to confirm the hypothesis that a systematic approach to develop BIM library provides efficient way to design, build, share, and communicate in the BIM process.

SCOPE & METHODOLOGY

The primary purpose of this paper is to find an efficient way to develop a systemic BIM library, focusing on the standard type of NATM tunnel construction. To coping with the purpose, extensive literature re-
views on recent technologies and trends of BIM library development, definition of BIM library, parametric modeling, NATM tunneling methods, and software applications have been implemented. Seven standard types of excavation works from a NATM tunnel project are developed as a holistic system library using Autodesk Revit and Digital Project. Lessons learned from the library modeling process and expected advantages of the proposed approach are summarized in the conclusions.

LITERATURE REVIEWS

BIM Library and Interoperability

Due to the increasing complexity of buildings and design processes, a systemized method of information exchange in the construction industry is increasingly important. At the aspect of microscopic level, a construction project is an assembly of a great number of objects. Meanwhile, BIM is usually called an intelligent object modeling providing automatic design ability and meaningful product information. In other words, a construction project is represented by objects and their relationships. The objects are represented as libraries in BIM. Therefore, libraries can be referred as the most basic element that represents the way to design, build, interoperate, share, and communicate in the BIM. Based on the motivation, various public and private associations such as The National BIM Library (NBL), ARCAT, RevitCity, SMARTBIM, Autodesk Seek, etc. provide free of charge online libraries and contents, the guidelines for development, and standard classifications. They provide various types of libraries using a specific domain of software application such as Revit, Bentley, ArchiCAD, Digital Project etc. Figure 1 illustrates an example of public libraries provided by NBL.

Fig.1. Screenshot shows a very simple example of concept walls being developed into detailed walls using predefined libraries (NBL, 2012)

However, these libraries are little available between different software applications in the real practice because respective applications have different (1) definitions of their basic objects, (2) capabilities representing geometry information, (3) parametric rules, and (4) property classification. The interoperability problems are frequently generated even in a single software application, according to different (1) design intend, (2) level of detail, (3) software skill, (4) standard compliance and so on. Considering BIM standards are not yet well defined and widely adopted, developing a standard library must be quite difficult.

LIBRARY DEVELOPMENT

Various BIM software applications provide a growing set of object-oriented parametric approaches with a predefined set of object families embedded object instances and parametric rules. These tools provide much more complex structures of object families and relations among them. In the library development process, a developer needs to decide (1) geometry representations (extrusion, blend, revolve, sweep, and swept blend), (2) relations (assigns, decomposes, associates, define, connects, etc.) among objects, (3) properties (material, performance, contextual properties) of objects, and (4) metadata and data structure for information management.

Parametric modeling equipped in most commercial BIM software applications is a useful tool to develop a library. Parametric modeling, as opposed to explicit modeling, has been early used to design and engineer products in diverse manufacturing industries. Parametric modeling involves the definitions of objects and relationships among objects. These definitions and relationships enable a developer to explore a range of design options using underlying parameters.

The parametric modeling capability proposes easy modeling process in generating intelligent objects without complex programming, in coordinating automatic changes, and in maintaining consistency. In parametric design, instead of designing an instance of a building element, an object is defined using parameters involving distance, angels, and rules like attached to, parallel to, and distance from. These relations allow each instance of an element class to vary according to its own parameter settings and contextual relations. Well-defined parametric rules enhance design and engineering productivity, allowing low-level changes to update automatically. However, frequently the predefined approaches make it difficult to define a new rule, because their pre-defined approaches are customized for building families that do not allow some special cases. In other words, the predefined approaches are complete only for the most standard types of a building construction such as column, beam, slab, window,
door, etc. The parametric modeling based approach involves the following limitations:

1. Inflexible predefined rule sets
2. Limited objects and extensibility
3. Interoperability issues
4. Professional knowledge and skill
5. Considerable effort, time, and cost

NATM Tunnel

The New Austrian Tunneling Method (NATM), also commonly referred to as the Sequential Excavation Method (SEM) uses the inherent strength in the rock mass to support the roof during excavation. Because this self-supporting capability achieves economy, flexibility in uncovered ground conditions, and dynamic design variability, NATM is widely applied for underground structures. NATM tunnels are largely dependent upon round length, types of support, and ground conditions such as shear strength, deformation, and groundwater level.

Excavation methods and supporting patterns are predefined using "types" in the planning phase. As ground conditions deteriorate, the type number increases, the number of supporting processes (such as rock bolts, steel plates, and forepoling) increases, and the length of excavation per cycle decreases from 3.5 meter to 1.0 meter.

Seven types (e.g., Type-I, Type-II) are used as a standard tunnel in the Korean construction industry. The standard types provide a common platform for project participants to communicate in the field. Cross section of Standard Type -1 representing detailed dimensions and characteristics of tunnel shape is illustrated in Figure 2.

![Fig.2. Cross section of Standard Type-I representing detailed dimensions and shape](image)

Unlike a building project having vertically repetitive structure and very large numbers of elements, tunnel projects are characterized by (1) relatively small numbers of elements, (2) horizontally long and linear shape and (3) availability to other Standard Types.

Representative elements for tunnel structure frame in BIM are excavation lining, rockbolt, shotcrete, concrete lining, waterproof membrane, drainage channel, wall tile, perforated drainpipe, utility conduit cover, and concrete pavement, illustrated in Figure 3.

![Fig.3. Libraries development for a tunnel structure](image)

The different characteristics of the large scale of project might positively impact on the BIM approach. On the other hand, unlike a building project, these libraries are not embedded in a software package such as system families or component families that can be created and customized in an external library. For example, "concrete lining library" can be generated using a beam or wall library in the component families, which has quite different attributes. Although the individual library can be developed, it is rarely useful to represent the combined structure of a tunnel project. Therefore, a holistic approach is required to represent overall structure of tunnel projects. Parametric modeling capability can be available to define individual object's behavior and relationships among objects. This paper proposes a holistic BIM library concept to overcome the limitations from a commercial software application and the limitations from parametric modeling.

Holistic System Library

A BIM library might combine geometry information such as 2D, details, and 3D drawings with property information including dimensions, positions, standard codes, materials, etc. and product information including specifications, manufacturer, price and procurement, codes, and schedule. In this paper, a
holistic system library is defined as a systematic approach to integrate geometry, property, and product information into a single BIM library. The concept of a holistic system library is designed for the efficient approach to BIM throughout the project life cycle. Figure 4 illustrates an example of a holistic system library involving geometry, property, and production information.

Development of a holistic system library enables project participants not only to access consistent and high-quality information, but also to improve productivity and efficiency in the design and communication process. For example, information from a holistic system library can be exported and used in various field applications such as quality assurance using specifications, bills of material using quantity takeoff, detailed drawing generation using geometry information, and so on.

System Applications
Pilot Project
Development of a holistic system library is tested using a pilot project. The Samtan 1 tunnel is the longest tunnel (2,645 meter in the Samchuk direction and 2,619 meter in the Jeachen direction) in the Samchuk–Jeachen road construction in South Korea. The NATM tunneling method and seven standard types were employed in the project. Total duration was 48 months for the two-portal tunnels with two-lane roads.

AUTODESK REVIT BASED APPROACH
Autodesk Revit Architecture is the best known and current market leader of the use of BIM. An example of the holistic system library using Revit is illustrated in Figure 6. Individual libraries illustrated in Figure 3 are combined into a single Standard Type library. The holistic system library automatically generates geometry, property, and product information according to the predefined parametric rules. A reference line, center line of a tunnel having traverse and vertical slope is used to extend the holistic system library as the length of the applied Type. For example, if Type 1 is supposed to implement in the first 12 meter, a user extends the Type 1 system library into 12 meter in the reference line. Consequently, relevant information is automatically generated, which includes properties, quantities (total length, area, volume), cost and schedule data, etc. Figure 7 illustrates the process how the holistic system library implements.

Well-designed functionality, user-friendly interface, easily available libraries, presentation of complex shapes, and modeling methods, extensibility to Excel format and protocols are identified as its strengths. On the other hand, lot of trial and error for more than four months has involved in developing geometric shape and defining parametric rules due to the lack of (1) field experience, (2) understanding quantity takeoff, and (3) capability on supporting parametric modeling. Because libraries are not defined in system families or component families, a developer needs to define an object behaviors and attributes and drawing template one by one.

A structural frame is used for developing the tunnel structures because a tunnel project is composed of
repetitive operations and represented by a horizontally long linear structure. Automatic coordination parametric rule between objects built in the structure frame generates predefined tapered sections. The automatic coordination rule causes 0.5% of error in calculating quantity. Due to inflexible rule sets provided by Revit, it has remained as the unsolved limitation hindering the reliability of accurate quantity takeoffs. Limited object sets and relatively large scalability are identified as limitations of Revit based approach to development of a holistic system library.

![Fig.7. Implementation of a holistic system library representing a reference line and information generation according to predefined parametric modeling in Revit](image)

**DIGITAL PROJECT BASED APPROACH**

Digital project is the world's most widely used parametric modeling platform in various industries. It is appropriate for a large project required elaborate custom parametric objects. It support visual basic for application (VBA) scripting and a strong application programing interface (API) which are useful for developing add-on programming and facilitating integration of specification for cost estimating. On the contrary to Revit, a developer arbitrarily defines diverse parametric rules and models any type of surface using points, lines and faces. Developing process of a holistic system library involves generating testing lines and points, defining input elements for the lines, developing object section and volume, defining parametric rules a developer represents, and testing and modifying. Trial and error processes are also required, but Digital Project can reduce considerable time in the processes comparing with Revit. Error can be significantly reduced by the detailed definitions of input elements and by VBA and API tools. Systematic data structure on the holistic system library should be managed to reduce overall scalability. Complex user interface, high initial cost, and limited open library are weaknesses of the software application. Figure 8 illustrates Digital Project based approach to the holistic system library.

![Fig.8. Implementation of a holistic system library using strong parametric modeling ability in Digital Project](image)

**CONCLUSIONS**

As construction projects become more complicated, increasingly specialized, and large in scale, collaboration between project participants is getting more and more emphasized over last few years. The collaboration tools for participants might vary, but traditional drawings and specifications play an important role. BIM technologies have introduced both new challenges and opportunities in the construction industry. While meaningful BIM can be accomplished by collaborative effort of project teams from the very beginning of construction projects, current BIM environment is immature to fully support diverse demands from various project teams.

Development of BIM library and contents has been regarded as one of the most basic requirement for the wider adoption of BIM. Based on the literature reviews and applications to commercial software, this paper proposes a holistic system library concept in developing BIM library. Many trials and errors and more than four months of development process have been implemented in order to develop the holistic system library appropriate to standard tunneling works. Public users can save considerable time and effort and in addition have rich product information through opening the holistic system library in online. The following benefits can be achieved by the approach of holistic system libraries;

1. Reducing interoperability limitations in a single software application and scalability limitations at a high level of detail
2. Saving considerable time, effort, and money required for develop a library
3. Suggesting qualified and consistent standard data across the construction industry
4. Sharing and maintaining information with a highly effective way
5. Allowing project teams to facilitate BIM technologies in the various construction areas
(6) Promoting collaborative environment throughout the project life cycle with an effect and efficient manner.

More application areas such as standard types of road or bridge construction and quantitative measurement on the benefits remain in the future extension of the research.

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References
Constructing as-is BIMs from progressive scan data

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Purpose Building Information Models (BIMs) have the potential to support various engineering applications (e.g., building energy analysis, renovation and retrofit planning, and facility management) in the facility operation phase. It is important to keep the information stored in as-is BIMs accurate and up-to-date. Laser-scanning technology is able to capture the as-is geometric condition of a facility in a timely manner. Hence, the laser scan data can be used as the reference to construct an as-is BIM. However, due to the occlusions caused by furniture, machinery, and building components, a single laser scan might only capture a partial view of a facility, which limits the value of laser scan data in the construction of as-is BIMs. Method In order to overcome this limitation, we propose to perform multiple laser scans of a facility during the construction, renovation or retrofit processes, and fuse the laser scan data captured at different times to create as-is BIMs. The purpose of this paper is to develop a formal approach to evaluate and compare the progressive laser scan data, and identify the value of using progressive laser scan data to create an accurate (i.e., the as-is BIM represents the actual as-is geometric condition of the facility) and complete (i.e., the as-is BIM contains all the components required to be modeled for the facility) as-is BIM. Results & Discussion We conducted a case study to present the process of creating an as-is BIM from progressive laser scan data, and identified the tasks that could be automated. We selected a research lab that was recently renovated as the testbed. In the case study, we performed multiple laser scans during the renovation process of the research lab to capture the geometric information of the lab at different phases of the renovation process. Figure 1 shows examples of the progressive laser scan data of the research lab. We formally assessed the progressive laser scan data in terms of their geometric accuracy and the represented components. The results showed that the progressive laser scan data can be used to eliminate static occlusions introduced during the construction, renovation or retrofit processes, and can be used to generate a complete view of the facility that covers all visible (e.g., walls, ceilings, floors) and invisible (e.g., air ducts, water pipes that are hidden behind the finished surfaces) components with accurate geometries.

Keywords: information technology, progressive laser scanning, as-is BIMs

INTRODUCTION

Used as the semantically rich representations of facilities, Building Information Models (BIMs) are capable of providing the as-is condition of facilities to support various operation and maintenance activities. However, in order to utilize BIMs in the facility operation phase, it is important to keep information stored in BIMs accurate and complete, since the documented facility information quickly becomes outdated due to changes happening in a facility over time. While it is possible to construct as-is BIMs directly from design drawings, many buildings do not have up-to-date design drawings available. The renovation, maintenance and repair activities might change the configurations of buildings, and these changes are not recorded in a consistent way. Another way to construct as-is BIMs is to update the as-designed model developed in the design phase of a facility into an as-is model. However, since a facility does not always get constructed exactly as the design specifies, extensive surveying is needed to measure the differences between the as-designed model and the as-built conditions. As an alternative to these approaches, laser scanning technology has been widely used in the industry to capture the detailed as-is conditions of facilities. Laser scanning technology has the capability to efficiently capture the 3D geometry of a facility in the form of point clouds. In current practice, point cloud data is used as a reference to manually generate as-is BIMs with modeling tools (e.g., Revit, ArchiCAD). The general modeling process is composed of three steps: (a) manually identifying the building elements to be modeled from the point cloud data (e.g., finding the points belonging to a pipe that needs to be modeled); (b) tracing the points to determine the location and the dimension of the building elements; and (c) modeling the elements with the modeling tools. This general modeling process is limited by the occlusions that existed when the point cloud data was collected. Due to the occlusions caused by temporary construction materials/equipment, furniture and building elements, the elements to be modeled might not be visible or only be partially visible in the point cloud data captured at a single point in time. For example, HVAC air ducts, which are installed above the ceiling tiles in a facility, would not be visible in the laser scans performed after the installation of the ceiling tiles.
Research studies have been performed concerning the creation of BIMs from point cloud data. Tang et al. (2010) proposed an automated process to convert point cloud data into a BIM. This process is divided into three steps: (a) fitting geometric primitives to point cloud data; (b) recognizing objects from point cloud data; and (c) establishing the relationships among different elements. Currently there is no state-of-the-art method that can be solely used to accomplish all the three steps of the automated process to convert point cloud data into as-is BIMs. A wide variety of methods have been proposed to recognize and extract planar surfaces from the point cloud data. There is a sizeable amount of work done in the computer vision domain to identify and extract 3D objects from the point cloud data based on the features, such as spin-images and shape descriptors. Following these methods, the identified planar surfaces or 3D objects can be used to form the elements in as-is BIMs. However, the occlusions existing in a scene can challenge the results obtained from these approaches. When a facility is progressively scanned over time, the likelihood of having the same occlusions at exactly the same parts of the building components is likely going to be reduced and hence would likely result in a more complete depiction of the scene.

In order to capture a complete view of a facility, we propose to scan the facility at different times while the facility is under construction or major renovation/retrofit. The point cloud data captured progressively over time is referred to as progressive laser scan data in this paper. To evaluate the benefits of using progressive laser scan data to create as-is BIMs, we used a research lab that was recently renovated as the testbed and progressively scanned the lab at different phases of the renovation process. The progressive laser scan data has been evaluated in two aspects: (a) the accuracy of the geometric information provided by the progressive laser scan data; and (b) the completeness of the geometric information that the progressive laser scan data is able to provide in order to model the required building elements in as-is BIMs. In this paper, we mainly focus on the completeness analysis of the progressive laser scan data, since the accuracy analysis cannot be performed until the objects are identified and recognized from the point cloud data. We assessed the completeness of the progressive laser scan in two steps: (a) identifying the building elements in the point cloud data that were captured at a certain time; and (b) evaluating whether building elements are fully visible, partially visible or invisible in the progressive laser scan data. The hypothesis here is that with the progressive laser scan data, one would expect to obtain a more complete view of building elements than using the point cloud data captured at a single point in time. The overview of the case study and its associated research findings are discussed in details in the following sections.

**CASE STUDY OVERVIEW**

A case study was conducted on a four month renovation project in a one hundred year old university campus building. In this project, three adjacent rooms were renovated to accommodate a high-tech research lab. The scope of this renovation project included the installation of high-end analytics equipment, 3D immersive visualization equipment and a new HVAC system. As the renovation was progressing, the research team visited the renovated space on several occasions and performed multiple laser scans to capture the interior of the research lab at different phases of the renovation process. At each point in time, the research team performed multiple scans from different locations to cover all the interior surfaces of the lab. Figure 2 shows a portion of the
progressive laser scan data captured in the research lab from May 2011 to August 2011.

As seen in Figure 2, the point cloud data captured at different times contain different geometric information for different building elements. With the renovation in progress, additional building elements were installed in the lab and are shown in the corresponding point cloud data. Those installed elements might obscure the vision of the laser scanner, and thus caused various occlusions in the point cloud data. For example, the air ducts were installed above the ceiling of the research lab. The point cloud data captured in May only contains parts of the air ducts since not all of the ducts were installed at that time. The point cloud data captured in June shows all the air ducts, since they were all installed by that time. However, the air ducts are invisible in the point cloud data captured in July and August because of the occlusions caused by the newly installed ceiling tiles.

In addition to the building elements which might be invisible in the progressive laser scan data, the building elements that are visible in all the progressive laser scans might also lack sufficient geometric information for modeling. For example, as seen in Figure 2, the walls, windows and doors are visible in all the point cloud data captured between May to August. Modeling of these elements would require certain attributes (e.g., dimensions, locations) to be extracted from the point cloud data. However, due to the occlusions or noise in the point cloud data, some of the required attributes are invisible or partially occluded in some of the scans. In both cases (i.e., visible and invisible elements), the modelers might not have all the required geometric information (e.g., shape, location, dimensions) from the laser scan performed at a single point in time. The problem highlights the opportunity of combining the point cloud data captured at different times in order to remove the occlusions that can result in visible building elements with partially missing geometric information or invisible building elements. A detailed assessment of the progressive laser scan data is presented in the next section.

ASSESSMENT OF THE PROGRESSIVE LASER SCAN DATA

In this section, we describe the work we have done to understand the completeness of the information required to model building elements from progressive laser scans. The assessment has been performed from two perspectives. The first part of the assessment is called the visibility analysis at object level and included understanding whether the building elements to be modeled are visible, partially visible or invisible in a scene, and labeling them as such. The second part of the assessment is called the visibility analysis at attribute level, which incorporated analysis of attributes required to model a given building element and performed only for the building elements that were labeled as partially visible in the object level analysis.

Visibility analysis of the progressive laser scans at object level

We reviewed the progressive laser scan data and identified three labels to classify the building elements captured in a given laser scan:

(a) **Fully visible**: A building element in a given point cloud data is completely visible for all the attributes required to model that building element. One example of this category is shown in Figure 3(a). In this example, the wall is labeled as fully visible since all dimensions (length, width and height) as well as its location are fully seen in the point cloud data without any occlusions.

(b) **Partially visible**: A building element in a given point cloud data is partly occluded and at least one of the attributes required to model that building element is missing in that scan. As seen in Figure 3(b), the right part of the wall is missing in the point cloud data, which limits a modeler to see the boundaries of the wall as well as to get the length of the wall. Hence the wall shown in Figure 3(a) is labeled as a partially visible element.

(c) **Invisible**: A building element cannot be seen in a given point cloud data. When a building element is labeled as invisible, it might be either not installed at the time when the laser scan was performed or fully occluded by other objects (e.g., construction material/equipment and surrounding building elements).
Fig. 3. An example laser scan showing two walls labeled as fully (a) and partially (b) visible

We analyzed the building elements in each of the progressive laser scans in terms of their visibility and categorized them using the labeling scheme introduced above. In this paper, we report the work in relation to the architectural elements, i.e., doors, windows, lighting fixtures, ceilings and walls. The floor plan of the research lab is shown in Figure 4, where the architectural elements are shown with their IDs. These IDs is used to label their visibilities in each scan.

Fig. 4. The floor plan of the research lab with the building elements shown with their IDs

The results of this analysis are shown in Figure 5. From May to August, the research team scanned the site at six different times. At each time, the research team scanned the site from different locations and registered the point clouds from each scan together into the same coordinate system. Hence, each laser scan shown in Figure 5 is referring to the registered point cloud data that was captured at a single point in time.

Fig. 5. Visibility analysis of building elements at object level

As shown in Figure 5, among the seven laser scans performed at different phases of the renovation process, none of them solely is capable of providing all of the architectural elements as fully visible. Out of the eleven walls in the lab, wall W1-N is partially visible in all of the seven laser scans. In order to get a full view of the rest of the walls, more than one laser scan must be performed at different times. Out of the five doors in the lab, three of them are fully visible.
visible in all of the seven laser scans. Door 5 is visible only in the point cloud data captured on August 14, because it was not installed until August. Due to the occlusions caused by the surrounding building elements and temporary equipment, there is no laser scan that is capable of presenting window 1 as fully visible. The ceiling tiles and lighting fixtures are invisible in the laser scans performed before July, whereas the laser scans performed in July and August successfully capture the geometric surfaces of ceiling tiles and light fixtures, but fail to fully capture the raw ceilings (i.e., raw ceilings are labeled as invisible or partially visible in these laser scans). The reason behind it is that the ceiling tiles and lighting fixtures were not installed until July, and after they were installed, they occluded the raw ceilings, which made the raw ceilings invisible or partially visible. The major benefit of progressive laser scanning is seen in such cases where multiple scans can be utilized to get a complete view of the elements that are partially captured in different scans to model them with as-is dimensions. Therefore, in order to model different building elements in as-is BIMs, we need to refer to the point cloud data captured at different times and select the point cloud data that is able to provide the most complete view of the building elements.

Visibility analysis of the progressive laser scans at attribute level

As seen in Figure 5, some of the building elements, such as wall W1-N and window 1, are partially occluded in all of the progressive laser scans. Since there is no point cloud data that is capable of providing a full view of such elements, an alternative is to retrieve the geometric information from the laser scans performed at different times, and combined the geometric information together to model the building elements that are partially visible. Figure 6 gives an example of how point cloud data captured at different times and combined the point cloud data that is able to provide the most complete view of the building elements.

Fig. 6. An example of Wall W1-N and Window1 shown in the point cloud data captured at two different points in time

According to the visibility analysis of the progressive laser scans at object level, the north wall of room 1 (W1-N) is partially occluded in all of the progressive laser scans. Therefore, in this section we looked at wall W1-N in more details. We first identified the attributes that are required to model the geometric representation of wall W1-N in the as-is BIM, and then evaluated each of the progressive laser scans in terms of the visibilities of these attributes in the scan data.

In order to identify the attributes for modeling wall W1-N, we referred to Industry Foundation Classes (IFC), which is an open data model standard to represent and exchange building information. In the IFC schema, a wall can be presented by the IfcWallStandardCase class. The 3D shape of a wall in the IfcWallStandardCase class could be modeled by the sweep representation approach, where the 3D shape of the wall is constructed by sweeping the 2D surface (i.e., the bottom of the wall) along a certain direction. As seen in Figure 7, in order to model the wall in the IfcWallStandardCase class, the following attributes are required: (a) Xdim, i.e., the length of the wall; (b) Ydim, i.e., the thickness of the wall; (c) ExtrudedDirection, i.e., the direction of the extrusion; (d) Position, i.e., the position of the wall, which is usually defined by the 3D coordinate of the center of the swept area, and (e) Depth, i.e., the height of the wall.
We used the same labeling scheme (fully visible, partially visible and invisible) to investigate the attributes of wall W1-N presented in the progressive laser scan data. The results of the analysis are shown in Figure 8. Among the seven laser scans performed at different phases of the renovation process, only one scan captures the length of the wall as fully visible. In the other laser scans, the length of the wall cannot be fully retrieved, since the edges of the wall are occluded. The position of the wall can be derived from the point cloud data by finding the interaction of wall W1-N with its adjacent walls. The height of the wall is partially visible in the laser scans in July and August, since the ceiling tiles that were installed in July occluded the top part of the wall. In most of the cases, the extruded direction is vertical, and perpendicular to the floor ground. Since we can get the floor plan from the progressive laser scans, the extruded direction is visible in all of the progressive laser scans. However, the thickness of the wall is missing in all of the progressive laser scans. The reason is that laser scans were performed at the interior of the research lab, and the exterior surface of the lab was not captured. Hence, one way to get the wall thickness is to scan the exterior surface of the lab, and then register the interior and exterior scans together. Another way is to fuse the point cloud data with other data sources, such as design drawings or product submittals, to get all the required attributes.

According to the analysis, different point cloud data might contain different geometric information of the partially visible elements. Although a building element is partially occluded in all of the progressive laser scans, it is still possible to retrieve all the required attributes from different scans and combine them to model the geometric representation of building elements. For instance, the laser scan performed on July 21 provides the attributes, i.e., the length of the wall, the extruded direction, and the position, for modeling wall W1-N, whereas the laser scans performed in May or June fully capture the height of the wall. Although the thickness of the wall cannot be gained from the progressive laser scans, we can refer to the other data sources, such as design drawings, or specifications to get this attribute. Therefore, combining the progressive laser scans and the other data sources (e.g., specifications, design drawings), we could gather all the required attributes to model the wall in an as-is BIM.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Progressive Laser Scan Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xdim (length)</td>
<td>0 0 0 0 0 1 1</td>
</tr>
<tr>
<td>Ydim (thickness)</td>
<td>0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Depth (Height)</td>
<td>0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Extruded Direction</td>
<td>0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Position</td>
<td>0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

**CONCLUSIONS AND FUTURE WORK**

Point cloud data captured by laser scanners can be used as the reference to create as-is BIMs. However, the changing facility environment and the dynamic construction or renovation process introduce obstructions in the point cloud data and obscure the elements that need to be modeled. This problem highlights the opportunity of using progressive laser scan data to create as-is BIMs. We conducted a case study to assess the completeness of the point cloud data captured at different times and identify the value of using progressive laser scan data to support the construction of as-is BIMs. The results indicated that the progressive laser scan data can be used to eliminate occlusions introduced during the construction, renovation or retrofit processes, and can be used to generate a complete view of the facility that covers all visible (e.g., wall, ceiling, floor) and invisible (e.g., air ducts and water pipes that are hidden behind finished surfaces) elements.

The future work of this research is to develop a formal approach to configure the progressive laser scans and use it to help the construction of as-is BIMs. To develop such an approach, the first step is to develop the reasoning mechanisms to assess the quality of the progressive laser scan data in terms of accuracy and completeness and configure the scans captured at different points in time in order to get all the required attributes for the modeling activities. In addition, point cloud data only provides geometric information, whereas an as-is BIM needs a variety of other facility information, such as material information, construction cost, warranty information and so on. Hence, in order to construct a semantically rich as-is BIM, information from other data sources (e.g., specifications, project cost database, product submittal) need to be extracted and fused into the as-is BIM. In the second step, we will identify the data sources that are capable of providing the required facility information for the as-is BIM, and de
velop a framework to encode the knowledge and information coming from different data sources (e.g., specifications, point cloud data, design drawings) into the process of creating a complete and accurate as-is BIM.

References

Dynamic Simulation and Visualization for Site Layout Planning

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Purpose
In recent years, construction projects have become more complex and time-driven, especially with the rapid rise in the number of active partners involved in each project. Space is regarded as a limited resource on construction sites. Proper planning for site layouts ensuring construction activities can be executed safely and efficiently is until now a time-consuming manual process. Site layout planning relies primarily on the knowledge and expertise of the planner, and is seldom subject to optimization efforts. Often, however, slight modifications to the original site layout plan, can mean limited space resources are allocated more efficiently, costs are reduced, and/or work efficiency is increased. Although construction site layout planning is an important pre-activity, systematic analysis to determine optimal space allocation is difficult because of the complexity of the situation, arising from the large number of engineering resources to be factored-in, and interrelated planning constraints. Space availability on any construction site needs to be considered in relation to scheduling, productivity loss due to path interference, and space constraints.

Method
This is a 4D-site-layout planning system based on the Monte Carlo method1 designed to solve space issues in construction sites, and to assist the planner in obtaining the optimal site layout plan. Monte Carlo analysis was executed to iteratively evaluate a deterministic model. This method is often used when a model is complex, nonlinear, or involves a significant number of uncertain parameters. The Monte Carlo simulation presumes that various steps involved in forming a network plan, and estimating the characteristics of the probability distributions for the various site layout plans have been completed. Formulas associated with the generation of normally distributed transportation hours and distances were used.

Results & Discussion
The implementation of this system was carried out in the MicroStation Visual Basic for Applications (MVBA) environment and encapsulates the complicated planning and optimization functions into five easy-to-use modules including management, layout planning, visualization, simulation and analysis. In our system, users can observe simulations of the entire construction process. For each simulation run, the total transportation time and distance of resources is recorded and evaluated, and then a Monte Carlo analysis is performed by the system in order to find an optimal site layout plan. Since space constraints affect the site layout of resources, and influence productivity on the construction site, it is essential that possible site layouts are generated and analyzed in advance, so that the available space can be used more efficiently. Furthermore, efficient construction site planning involves the simultaneous assessment of schedule and site layout so that space can be used more efficiently and dynamically. In response to these needs, this research developed a 4D-site-layout-planning system to assist planners in developing efficient site layouts, and to monitor the results dynamically and visually.

Keywords: layout planning, optimization, Monte Carlo method, 4D visualization

INTRODUCTION
In recent times, construction projects have become more complex and time driven, especially with the rapid rise in the number of active project participants involved in each project. The construction workspace layout plan not only affects the construction process and its efficiency, productivity, rate of utility of equipment resources, mobility of materials and labor, it is also a major factor that determines construction costs. Therefore, achieving optimal site layouts within the spatial limitations of each construction site has become an important step before the engineering planning stage. Kaming et al. (1998) indicated that space conflicts have been identified as one of the major causes of productivity loss in construction1. Sanders et al. (1989) reported efficiency losses of up to 65% due to congested workspaces and losses up to 58% due to restricted access2. Thus it is widely accepted that the site workspace layout exerts a strong influence on construction efficiency. Some researchers have proposed different optimal solutions to solve these workspace and layout planning problems. Although mathematical optimization procedures have been developed to produce optimal solutions, they have only been applicable to small-sized problems. Artificial intelligence techniques have already been applied to solve real-life problems. On the other hand, heuristic methods have been used to produce better but not optimal solutions for large problems. An optimization model has been developed to solve the site layout planning problem, while simultaneously considering safety and envi-
rnonmental issues, and actual distances between facilities. Nowadays, there are many researchers who utilize simulation systems to determine optimal workspace layout plans. In particular, 4D technology, which shows how 3D models will change as the construction progresses over time, has emerged rapidly. This is mainly due to the increasing recognition from the construction industry of the benefits of using the 4D applications, such as increased productivity, improved project coordination, and the optimization of on-site resource allocation. Thus, 4D technology can have a positive impact on both pre-construction and construction phases, because it assists planners in producing improved planned projects by allowing them to see how their plan will evolve. Chau et al. (2005) developed a 4D site management model that incorporates the 4D concept into fields of construction resource management and dynamic site planning. Akinci et al. (2002) also executed similar research which reduced non-value-adding activities resulting from time-space conflicts. A time-space conflict analysis based on a 4D production model was then proposed. Mallasi’s (2004) research developed an innovative computer-based tool dubbed PECASO. This system has potential for assisting site managers in the assignment and identification of workspace conflicts. However, large numbers of building components, workers, equipment and materials share limited space during construction. Since space constraints are likely to affect efficient movement of construction site resources, it is essential to detect and analyze workspace conflicts in advance, such that the available space can be used more efficiently. Normally, the creation of a construction site layout plan relies primarily on the knowledge and expertise of the planner, and is hardly subject to optimization efforts. This paper presents a semi-automatic approach to assist the site layout plan generation process. This research developed a 4D site layout planning system which provides an effective visual environment for the presentation and analysis of space utilization and activity statuses, using techniques such as 3D visualization and 4D simulations with different color codings. The integration of flexible Monte Carlo analysis into a constraint-based simulation concept to determine optimized construction site layout plans is also presented in this paper. Effective site layout plans facilitate efficient resource allocation and result in cost-reduction and increased work efficiency.

**RELATED WORK**

Construction site layout problems can be described by constraint satisfaction which is a powerful paradigm for modeling complex combinatorial problems. Fig. 1 presents the most frequently-used optimization algorithms for site layout planning.

1. **Artificial Intelligence**
   - Yeh (1995) utilized the annealed neural network model to solve the construction-site layout problem.

2. **Mathematical Model**
   - Montreuil (1990) proposed a mathematical programming modeling framework for integrating layout and undirected flow network designs.
   - El-Rayes and Said (2009) developed an approximate dynamic programming model capable of searching for and identifying global optimal dynamic site layout plans. The model applies the concepts of approximate dynamic programming to estimate the future effects of layout decisions in early stages on future decisions in later stages.

3. **Heuristic Algorithm**
   - Foulds and Robinson (1978) utilized the deltahedron approach to solve the layout problem. After a planar graph was developed to identify adjacent departments, a heuristic procedure was applied to construct a block layout that satisfied these adjacency relationships.
   - COFAD is a modification of CRAFT and includes moving costs for all alternative material handling systems (MHS), thereby integrating the material handling system selection problem with the layout problem.
   - Kaku et al. (1991) used a K-median heuristic to cluster departments into groupings in such a way that inter-group interaction would be minimized where the number of floors determines the number of groups.
   - Goetschalckx (1992) developed an efficient method for generating a rectangular block plan that meets area requirements from the dual of a planar graph.

4. **Simulation**
   - Monte Carlo simulations can be applied to tackle the merge-event bias problem. Fan
and Kumar (2010) proposed the use of the Monte Carlo method to simulate the variation of coordinates of the locating contact points. The Site Layout Planning Model can be divided into four main steps as shown in the following sections.

**Site Layout Plan Creation**
Construction engineers have to properly allocate uses and activities to the various construction spaces, such as Building Areas, Store Areas, Parking Areas, Office Areas and Paths, to minimize the costs of labor and transportation of equipment. Users can plan and create various 3D site layout plans in the 4D Site Layout Planning System.

**Constraint-based Simulation**
The constraint-based simulation approach was adopted to overcome the limitations of fixed activity graphs and resources availability.

**Monte Carlo Analysis**
Monte Carlo analysis was executed for iteratively evaluating a deterministic model. This method is often used when a model is complex, nonlinear, or involves more than just a couple of uncertain parameters. The procedures of Monte Carlo Simulation presume that the various steps involved in forming a network plan, and estimating the characteristics of the probability distributions for the various site layout plans have been completed. Formulas associated with the generation of normally distributed transportation hours and distances were used. The concept of movement paths for equipment and workers is shown in Fig. 3, and the related formulas are defined in Eq. (1), Eq. (2) and Eq. (3).

### Transportation Distance
The system can calculate the total transportation distance via Eq. (1) and Eq. (2). The distance \( d_{i,i+1} \) between Pi and Pi+1 points is given by the formula Eq. (1): Assume \( Z=0 \), in which \((X_i, Y_i)\) is coordinates of Pi and \((X_{i+1}, Y_{i+1})\) is coordinates of Pi+1.

\[
d_{i,i+1} = \sqrt{(X_i - X_{i+1})^2 + (Y_i - Y_{i+1})^2}
\]  

The system will then perform a summation to calculate the total transportation distance (D) as shown in Eq. (2), in which N is the number of points.

\[
D = \sum_{i=1}^{N} d_{i,i+1}
\]

### Transportation Time
When the system obtains the total transportation distance (D) of equipment and labor, it can then automatically calculate the transportation time (T) according to their average velocity (V) as shown in Eq. (3).

\[
T = D/V
\]
SYSTEM DESIGN AND IMPLEMENTATION

As shown in Fig. 4, this research takes advantage of Building Information Modeling (BIM) technology to enable the 4D site layout planning system to generate an efficient site layout plan. This system is divided into three tiers: the first tier consists of the BIM models, which describe and store information about entire engineering projects and the results of site layout planning; the second tier is the Bentley MicroStation which provides functions for 2D/3D Data Acquisition, Storage, Editing, Processing, Analysis, Display; the third tier is the 4D site layout planning system developed in this research. The implementation of this system was carried out in the MicroStation Visual Basic for Applications (MVBA) environment, and encapsulates the complicated planning and optimization functions into five easy-to-use modules. These five modules are:

- **Management:** This module is responsible for managing project information and system data, including project schedule and data, resource allocation, 3D models, and site layout planning results.
- **Layout Planning:** This module provides functions for users to create and define the size, location, purpose and exits of workspaces. The layout can be used to simulate and analyze usability and efficiency according to project schedules and resource allocation plans.
- **Visualization:** This system provides tools for defining the relationships between the objects in the 3D model and time schedule. This enables users to understand the processes of construction and resources transportation via 4D visualization. In addition, the system can provide the relevant project information through 1D text, 2D graph and 3D models.
- **Simulation:** In our system, users can observe simulations of the entire construction process. For each simulation run, the total transportation time and distance of resources is recorded and evaluated.
- **Analysis:** The constraint-based simulation is run repeatedly, and then a Monte Carlo analysis is performed by the system in order to find an optimal site layout plan.
DEMONSTRATION

Example

A simple construction project was used as an example to verify and demonstrate the functionalities of the 4D site layout planning system. The construction project is a 2-floor precast engineering project; the area of the construction site is 80m*42m. In this system, the quantity of the available resources was specified and limited according to the site layout plan.

Table 1 summarizes the simulated variables and constraints in this research. For each resource configuration, a Monte Carlo analysis consisting of many simulation runs was performed, with each run resulting in a different transportation path. From the results of the simulation, planners can select the best solution according to their objectives and their particular needs.

Table 1. Simulated variables and constraints

<table>
<thead>
<tr>
<th>Site Layout Plan</th>
<th>Labor</th>
<th>Excavator</th>
<th>Truck</th>
<th>Crane</th>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Plan B</td>
<td>10</td>
<td>1</td>
<td>2</td>
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</tr>
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</table>

Functionalities

The functionalities of this system can be divided into four parts as explained in the following section.

- Fig. 5 illustrates the main graphical user interface (GUI) of the 4D site layout planning system. Before starting the simulation, the user needs to define the resources available for the project. The user can easily manage the activity tree and its resources by creating and adjusting the relationships among the various activities and resources through the GUI, as shown in Fig. 5(a).

- The planner can create various site layout plans in the 3D visual environment for simulation and analysis. The 3D objects in the site model are represented in different colors, depending on their purpose and type. Fig. 5(b) shows the color scheme implemented in this work.

- The constraint-based simulation is then repeatedly run in order to find an efficient site layout. The resultant detailed transportation process can be easily combined with the 3D model of the project to generate 4D visualization as shown in Fig. 6.

- Fig. 7 shows the results of the Monte Carlo analysis conducted in this research. In this example, the shortest transportation time and distance is given by Plan B, as shown in Table 2 and Table 3. The application of Monte Carlo analysis does not guarantee the finding of an optimum solution. However, this approach enables one to analyze and visualize the various candidates of site layout plan, and clearly identify good solutions, albeit manually. Based on transportation times and distances for labor and equipment, one may say that Plan B is more efficient than Plan A.

(a) The GUI for simulation and analysis (b) The GUI for site layout planning and visualization

Fig. 5. The GUI of 4D Site Layout Planning System
FIG. 6. 4D visualization

FIG. 7. Results of constraint-based simulation

Table 2 Monte Carlo analysis results of Plan A

<table>
<thead>
<tr>
<th>Plan A</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time(hr)</td>
<td>18.02</td>
<td>18.41</td>
<td>18.86</td>
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<tr>
<td>Distance(km)</td>
<td>104.53</td>
<td>106.64</td>
<td>109.04</td>
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Table 3. Monte Carlo analysis results of Plan B

<table>
<thead>
<tr>
<th>Plan B</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
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<tbody>
<tr>
<td>Time(hr)</td>
<td>16.84</td>
<td>17.02</td>
<td>17.30</td>
</tr>
<tr>
<td>Distance(km)</td>
<td>98.13</td>
<td>99.15</td>
<td>100.57</td>
</tr>
</tbody>
</table>

CONCLUSION

Since space constraints affect the site layout of resources, and influence productivity on the construction site, it is essential that possible site layouts are generated and analyzed in advance, so that the available space can be used more efficiently. Furthermore, efficient construction site planning involves the simultaneous assessment of schedule and site layout so that space can be used more efficiently and dynamically. In response to these needs, this research developed a 4D Site Layout Planning System to assist planners in developing efficient site layouts, and to observe the results dynamically and visually.

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References


An integrated system for automated construction progress visualization using IFC-Based BIM

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Purpose Accurate and timely visualization of the progress of a construction project is a critical element for success. Current methods of data collection for progress visualization tend to be manual. These manual methods are not only error-prone but also time-consuming. Remote sensing technology has been used to resolve those problems related to collecting the data related to construction progress. Studies have shown that data collected for construction progress visualization via remote sensing technology can be effective. However, data corresponding to all as-built structural components must be collected in order to accurately visualize construction progress. This is impractical on real construction sites that usually are large, cluttered, and complex. This paper proposes an integrated system for the visualization of automated construction progress using IFC-based BIM and data which correspond to parts of as-built structural components acquired using remote sensing technology.

Method The system integrates measurement, analysis, and visualization of the progress of construction projects in four main modules. The first module extracts geometric and schedule information from IFC and converts the extracted information into a format acceptable to the MATLAB. The second module measures project progress utilizing converted geometric information and 3D data acquired from construction sites. The third module analyzes, verifies, and updates project progress using schedule sequences and topological information in IFC. The last module compares the as-built and as-planned schedules and visualizes current project progress.

Results & Discussion The proposed integrated system has been verified to demonstrate its robustness by using data corresponding to a part of as-built structural components acquired from real construction sites. The results reveal that the proposed integrated system can accurately and effectively visualize current project progress information from data which correspond to part of as-built structural components. The visualization results can be used as a decision-making tool by project stakeholders.

Keywords: automation, industry foundation classes, progress visualization

INTRODUCTION

It has been shown that accurate construction progress measurement is critical to the success of a building project. Recently, studies have demonstrated that remote sensing technology can be used to obtain 3D data about construction progress and have proven the efficiency of the data collection process. In addition, 3D data acquired using remote sensing technology can be effectively compared with the building project's 4D as-planned building information model (BIM), which integrates an as-planned schedule with a 3D model created using computer-aided design (CAD). By doing this, one can obtain construction progress information automatically from the construction site.

Previous studies have shown the possibility of construction progress measurement automatically by using remote sensing technology. However, the accuracy of the construction progress measurement is affected by a number of factors. First, because of the sensor's limited field of view, it is only possible to obtain 3D data corresponding to the as-built structural components that are located within this field of view. Second, in any building project, the structural components are arranged with some level of complexity, and there are likely to be various pieces of equipment and other objects located around the construction site. Thus, structural components that are physically within the sensor's field of view may nonetheless be blocked from the sensor's view. For these reasons, 3D data obtained by using remote sensing technology is incomplete. A study by Bosch found that only 83% of actual as-built steel components were recognized as such. In a study by Son and Kim, 88% (86 of 98) steel components were recognized as such. In research by Golparvar-Fard et al., part of an as-built wall was not recognized as such. In a study by Turkan et al., 98% of as-built concrete components were recognized as such. In order to resolve these problems, a process that includes obtaining a large number of 3D data sets from different positions and then merging them should be performed. However, merging multiple sets of data alone is not enough: The Son and Kim study, Golparvar-Fard et al., and Turkan et al. experiments used this method during the construction of a simple, small structure. Though accurate data about structural components was obtained, the method still failed to obtain complete 3D data. Thus, in the case of a larger or more complex construction project, it is impossible to obtain complete data. Therefore, the
above-mentioned problems will significantly affect one’s ability to obtain construction progress information.

This study proposes a verification process for construction progress measurement through utilizing information in a BIM to modify inaccurate construction progress information caused by incomplete 3D data. Methodologies related to construction progress measurement are provided in Section 2. In Section 3, field experiment results obtained by using the proposed verification process are presented. Finally, conclusions and recommendations for future research are provided in Section 4.

**METHODOLOGY**

Information extraction

In order to initiate the measurement of construction progress, relevant as-planned information from an IFC-based BIM and relevant as-built information from 3D data obtained by remote sensing technology should be extracted. IFC (Industry Foundation Classes) is a data model standard developed by BuildingSMART International Ltd. as an international information exchange standard. IFC2x Edition 3 (IFC2x3) is the latest official IFC release; it contains 653 entities and allows for complex relationships between these entities. Among the 653 entities in IFC2x3, entities that contain as-planned information for construction progress measurement should be filtered and mapped to the internal information structure within the data processing software. Also, 3D data obtained from the construction site using remote sensing technology contains not only as-built information for the building project itself but also for various objects at the construction site such as heavy equipment, materials, and so on. In terms of construction progress, as-built information refers to structural components. Therefore, a process called "structural component detection" is performed to extract 3D data about the building project’s structural components from the overall set of 3D data obtained from the construction site.

Extraction of as-planned information for construction progress measurement from an IFC-based BIM

To filter and map as-planned information for construction progress measurement to the internal information structure, entities that contain the geometric information for each structural component, the list of components related to each activity, the planned schedule of activities, the sequence that activities are executed in, and the spatial relationship between components should be defined. Among the 653 entities in an IFC file, IfcColumn, IfcBeam, IfcSlab, and IfcWall are the entities that represent the most basic structural components. Fig. 1 shows an example of the geometric information for a column in an IFC file. The entity IfcColumn (#473) associates IfcLocalPlacement (#438) with IfcProductDefinitionShape (#472). The number in parentheses represents the instance number in the IFC file in the figure. IfcLocalPlacement (#438) is used to define the placement of a component in relation to the placement of another component. IfcProductDefinitionShape (#472) contains the entity IfcShapeRepresentation (#471), which is used to define a specific kind of representation which represents a component shape. In this example, component shape is represented by IfcFacetedBrep (#443), the entity that defines boundary representation (B-rep). B-rep represents a component indirectly by its bounding surface. Surfaces that represent the component are defined by IfcClosedShell (#444), and the boundaries of each surface are defined by IfcFace (#455), which contains the entity IfcFaceOuterBound (#454). IfcPolyLoop (#453), which is contained within IfcFaceOuterBound (#454), is used to define the 3D coordinates of the boundaries of each surface. The example shown in Fig. 1, the column consists of six surfaces (#455, #458, #461, #464, #467, and #470). In the case of IfcFace (#455), this particular surface consists of four boundaries and its 3D coordinates are (63231.5, -33226.625, 5000), (63931.5, -33226.625, 5000), (63931.5, -33926.625, 5000), and (63231.5, -33926.625, 5000). Thus, the geometric information for each component is extracted from the IFC file by integrating the 3D coordinates of each boundary of the surfaces defined by IfcClosedShell.

After the geometric information for each structural component is defined, activity information related to each component should be defined to generate a 4D as-planned model. Activity information used to generate a 4D as-planned model includes the components related to the activity and the planned schedule of activities. Fig. 2 shows an example of the activity information related to each component in an IFC file. First, the components related to the activity are defined by IfcRelAssignsToProcess. IfcRelAssignsToProcess (#3646) includes the list of entities -- such as IfcColumn (#473), IfcColumn (#1487), and IfcTask (#3605) -- that connect an activity with its components. The figure shows that IfcTask (#3605) is related to IfcColumn (#473), IfcColumn (#1487), IfcColumn (#1283), IfcColumn (#1706), IfcColumn (#1541), IfcColumn (#1651), and IfcColumn (#1596).
Second, the planned schedule of activities is defined by IfcRelAssignsTasks\(^7\)\(^,\)\(^8\). IfcRelAssignsTasks (#3616) provides the as-planned schedule of activities by linking IfcTask (#3605), which is used to define the properties of a particular activity, and IfcScheduleTimeControl (#3606), which is used to define the scheduled start date, scheduled finish date, and scheduled duration of IfcTask (#3605). According to the example shown in Fig. 2, the scheduled start date is defined by IfcDateAndTime (#3609) as January 11, 2012 at 9:00 am; the scheduled finish date is defined by IfcDateAndTime (#3612) as January 31, 2012 at 5:00 pm; and the scheduled duration is 432,000 seconds.

An IFC-based BIM contains not only information for generating a 4D as-planned model but also information that can be used to verify the logical relationship between structural components such as the sequence that activities are executed in and the spatial relationship between components. Fig. 3 shows an example of the logical relationship between the structural components defined in an IFC file. The sequence that activities are executed in is defined by IfcRelSequence (#3644). IfcRelSequence (#3644) associates the relating activity, the related activity, the time lag between the two activities, and the sequence type. In this example, the relating activity (taken from Fig. 3) is IfcTask (#3605), the related activity is IfcTask (#3617), the time lag is 0 seconds, and the sequence type is "finish to start" (Finish_Start). This means that when IfcTask (#3605) is finished, IfcTask (#3617) will start and there will be no time lag between IfcTask (#3605) and IfcTask (#3617). The spatial relationship between components is defined by IfcRelConnectsElements\(^9\). In order to define connectivity, which describes two elements being physically or logically connected, IfcRelConnectsElements (#3654) specifies the relationship between a relating component and a related component. According to the example in Fig. 3, IfcColumn (#473), which is the relating component, and IfcBeam (#1816), which is the related component, are connected.

**Fig. 1.** An example of the geometric information for a column in an IFC file

**Fig. 2.** An example of the activity information in an IFC file

**Fig. 3.** An example of the logical relationship between structural components defined in an IFC file.
posed by Son et al.\textsuperscript{11} was used. Son et al.\textsuperscript{11} showed that combining the hue-saturation-intensity (HSI) color space with the support vector machine (SVM) proposed by Vapnik\textsuperscript{12} is useful for detecting concrete in color images. In this method, the database is transformed from red-green-blue (RGB) to HSI, and then a concrete color-model is constructed using SVM. Using the concrete color-model, 3D data corresponding to the concrete’s color is classified and extracted from the 3D data obtained from the construction site.

Fig. 3. An example of the logical relationship between structural components in an IFC file

Construction status recognition

After the information extraction process, a 4D as-planned BIM and 3D data about each structural component is used to recognize the construction status of each structural component. The process to recognize the construction status of each component consists of two stages: The first stage is 3D registration, which aligns the 4D as-planned BIM with 3D data about structural components, and the second stage involves matching the 4D as-planned BIM with 3D data about structural components to recognize constructed structural components. The 3D registration was performed by the approach proposed by Kim et al.\textsuperscript{13}. This approach provides a fully automated way to align 3D data with a 3D CAD model. The approach requires preprocessing for the 3D data and the 3D CAD model, respectively. After the preprocessing, the aligning of the preprocessed 3D data with the preprocessed 3D CAD model consists of two distinct steps: global registration and local registration. Then, by applying the transformation parameter determined by the global and local registration of the preprocessed 3D data, the coordinates of the original 3D data and the original 3D CAD model can be directly aligned.

Based on the registration result, a matching method that uses SVM is then used to recognize construction status. This method provides accurate results for construction status recognition regardless of the density of the 3D data. In this method, for each structural component, a subset of 3D data that represents that component is extracted from the overall 3D data set that has undergone 3D registration. Then, each subset of 3D data is classified according to predicted categories using SVM. The construction status of each component is then updated as follows:

\[
S_k = \begin{cases} 
1, & \text{if } A_k = P_k \\
0, & \text{otherwise} 
\end{cases}
\]

where \(S_k\) is the construction status of the \(k\)th component; \(k = 1, \ldots, l\), where \(l\) is the total number of components; \(A_k\) is the actual category of the \(k\)th component; and \(P_k\) is the predicted category of the \(k\)th component.

Construction status verification

The construction status of each structural component obtained through the aforementioned process may be inaccurate when the 3D data is incomplete. Thus, in order to measure construction progress accurately, a verification process is needed to modify the inaccurate construction status of any such component when that inaccurate status is caused by incomplete data. This verification process consists of two stages: Verification using the sequence that activities are executed in and verification using the spatial relationship between structural components. In verification using the sequence that activities are executed in, the construction status of structural components belonging to a preceding activity is modified. However, verification using the sequence that activities are executed in cannot modify the construction status of components belonging to the same activity. Hence, verification using the spatial relationship between structural components is necessary to modify the construction status of components belonging to the same activity. Through these two verification processes, it is possible to modify the inaccurate construction status of any such component.

Verification using the sequence that activities are executed in

The input for the first verification process is the construction status of each structural component obtained through the aforementioned process and the sequence that activities are executed in. IfcRelSequence defines preceding and following activities. This relationship means that a following activity will start when the corresponding preceding activity has completed. Thus, if at least one structural component related to a following activity is recognized as being constructed, all components related to the preceding activity are recognized as being constructed. Algorithm 1 uses the construction status of structural components related to a following activity to determine the construction status of components related to a preceding activity. The details of Algorithm 1 are given below:
Algorithm 1: Algorithm for verification using the sequence that activities are executed in.

1. Input: The construction status of each structural component and the sequence that activities are executed in, taken from IfcRelSequence in the IFC file.
2. Get the construction status of the structural components that are contained within the first IfcRelSequence, using the SVM matching method.
3. The modified construction status is derived from:
   \[ A_p(S_i) = \begin{cases} 1, & \text{if } \sum A_j(S_j) \geq 1 \\ A_p(S_i), & \text{otherwise} \end{cases} \]
   where \( A_p(S_i) \) is the construction status of the \( i \)th component of the preceding activity; \( i = \{1, ..., n\} \), where \( n \) is the number of components related to the preceding activity; \( A_j(S_j) \) is the construction status of the \( j \)th component of the following activity; and \( j = \{1, ..., m\} \), where \( m \) is the number of components related to the following activity.
4. Get the construction status of the structural components that are contained within the next IfcRelSequence, using the SVM matching method.
5. Repeat steps 3 and 4 until every IfcRelSequence has been checked.

Verification using the spatial relationship between components

The input for the second verification process is the modified construction status of each structural component obtained from Algorithm 1 and the spatial relationship between structural components. IfcRelConnectsElements represents the spatial relationship between structural components by defining relating and related structural components. This relationship shows the logical or physical relationship between a relating and a related structural component. If a related component is considered to be constructed, all corresponding relating components are considered to be constructed. Algorithm 2 uses the construction status of a related component to determine the construction status of a relating component. The details of Algorithm 2 are given below:

Algorithm 2: Algorithm for verification using the spatial relationship between structural components.

1. Input: The construction status of each structural component that was modified by Algorithm 1 and the spatial relationship between structural components, taken from IfcRelConnectsElements in the IFC file.
2. Get the construction status of the related structural components contained within the first IfcRelConnectsElements, using Algorithm 1.
3. The modified construction status is derived from:
   \[ R_g = \begin{cases} 1, & \text{if } R_d = 1 \\ R_g, & \text{otherwise} \end{cases} \]
   where \( R_g \) is the construction status of the relating component and \( R_d \) is the construction status of the related component.
4. Get the construction status of the related structural components contained within the next IfcRelConnectsElements, using Algorithm 1.
5. Repeat steps 3 and 4 until every IfcRelConnectsElements has been checked.

The eleven scans were then merged to obtain the overall set of 3D data from the construction site. Fig. 4(a) shows the merged 3D data from the eleven scans obtained from the construction site. To generate the BIM, Autodesk Revit™ (developed by Autodesk, Inc.) was used. Synchro (developed by Synchro Ltd.) was used to link the 3D geometric information of the building in the BIM with scheduling information and to export the BIM to the IFC file. The BIM used for the experiment is shown in Fig. 4(b).

The accuracy of construction progress measurement was measured by recall and precision rates. The recall rate is the percentage of structural components recognized as being constructed among actually constructed components. The precision rate is the percentage of actually constructed components among components that are recognized as being constructed. As shown in Table 1, the verification process consists of two steps that improve the accuracy of construction progress measurement, especially the recall rate. Without the verification process, the recall rate is very low since actually constructed internal columns and beams under the slab are recognized as being non-constructed because these components are blocked from the sensor’s field of view. Through the first verification step, the recall rate is significantly improved since actually constructed components in the first and second floor are recognized as being constructed. In the second verification step, the construction status of components in the third floor is modified. The recall rate in this study is higher than in previous research. For example, in our previous research, the recall rate was 88% without the verification process.
These current results indicate that the proposed verification process can improve the accuracy of construction progress measurement that is affected by incomplete 3D data caused by the limitations of the sensor’s field of view and the occlusion of structural components.

Table 1. Effect of verification process on accuracy of construction progress measurement

<table>
<thead>
<tr>
<th>Verification Results</th>
<th>Recall Rate</th>
<th>Precision Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Verification</td>
<td>52%</td>
<td>100%</td>
</tr>
<tr>
<td>First Verification</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td>Second Verification</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND FUTURE WORK

This study presented a verification process that uses information contained in an IFC-based BIM to improve inaccurate construction progress measurement caused by incomplete 3D data obtained from a construction site using remote sensing technology. To extract information for improving the accuracy of construction progress measurement, information that is needed for the recognition of each structural component’s construction status and for the verification process was defined. Based on the extracted information, the initial construction status of each component was recognized. The initial construction status of each component may be inaccurate due to incomplete 3D data. Therefore, verification using the sequence that activities are executed in (for components related to different activities) and verification using the spatial relationship between components (for components related to the same activity) was performed. The improvement in accuracy due to the proposed verification process was validated using incomplete 3D data obtained from a real construction site. The results indicate that the proposed verification process is capable of improving the accuracy of construction progress measurement; thus, construction progress can be effectively managed. In future research, the proposed verification process should be employed in various applications of construction progress management. Examples of such applications include construction progress visualization, actual progress calculation, and construction of an automated construction progress management system.

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References


BIM-Image-Based Indoor Localization Prototype

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Purpose In order to provide an economical indoor location detective technique, this study is uses photo images as the indoor spatial identification tags associated with the spatial information of the existing building information model (BIM), so that users can identify their locations via the camera on mobile device based on the real images. Method Unlike the wireless and radio frequency identification based indoor positioning techniques, this study applied the image recognition technique to indoor location detection. Three functional modules, namely, (i) BIM object location collector, (ii) spatial image management module, and (iii) vision-based location recognition module are developed. BIM object location collector takes the responsibility to automatically collect the location data from the IFC (Industry Foundation Classes) dataset of the existing BIM. Firstly, the spatial image management module provides an interface to clients for collecting spatial photos in buildings, and bind them with the location data transferred from the original building information model. Secondly, the recognizable features of the spatial photos can be analyzed by the vision-based location recognition module which is developed based on the D’fusion studio. According to the analyzed image features, the vision-based location recognition module can then recognize the frames of the visions captured by the mobile device camera. Once the frame is recognized, the corresponding spatial data can be retrieved. Results & Discussion Based on the designed architecture, a BIM-vision-based indoor localization prototype was developed as an android platform application running on the mobile device such as smart phones and tablets. Technique feasibility is continuously tested in the current phase. According to the basic test results, the prototype can identify the indoor locations of decorated spaces; however, once the indoor spaces lack of recognizable features, such as the empty spaces with blank and monotony walls, the recognition function failed. To overcome this defect, the Quick Response (QR) code, the trademark for a type of two-dimensional code, is used as a substitution of the photos for this prototype. Besides, since the location data is transferred from the existing building information model, data consistency can be ensured. In the future, the economic feasibility of this prototype will be analyzed to evaluate the cost-benefit ratio.

Keywords: indoor localization, BIM, image recognition, IFC

INTRODUCTION

The necessary of the indoor localization for maintenance phase of buildings is increased due to more facility management requirements such as administration of equipment, maintenance service, building health management and indoor emergency navigation requirements1. Because building spaces serve different functions with multiple facilities and equipment, the building administrator and maintenance engineers have to grasp the facility data distributed to building spaces and determine the maintenance strategies based on the space oriented information. However, because of the multiformity of building spaces, the facility management staff could not always connect facility management data, e.g. equipment repair records, to building spaces. Without the connection with the building spaces, the information is deficient for the facility management usage. Providing space information to facility management staff automatically could overcome this circumstance. On the other hand, space localization is also a critical technology for intelligent buildings. Proper services could be provided to the occupants if the user’s location is detected automatically. Accordingly, this study was aimed to develop an indoor localization system for building maintenance and operation usages. Several researches of positioning and localization technologies have been down well for outdoor and indoor applications. The Geographic positioning system (GPS) is the common technology adopted for positioning. While some studies have tested GPS which provides an accuracy of around one meter, it is costly and cumbersome which needs fixed ground stations and is only efficient outdoors1. Wireless LAN (WLAN), ultra-wide-band (UWB), and radio frequency identification (RFID) have been combined for an emergency navigation system in complex buildings1. Using image recognition technology, an outdoor/indoor vision-based localization system was developed for blind pedestrian navigation assistance5. Besides, several real-time localization systems (RLTS) based on distributed wireless sensor networks or RFID have been tested for indoor human position sensing3-7. However, combining different positioning technologies not only brings more complexities in system integration and user interface, but also inherits the natures of the costly initial investment and maintenance/operation costs, i.e., the total cost increases directly in the great space.
amount building. Moreover, additional devices are needed for users, such as RFID readers\textsuperscript{5-7}, sensor receivers etc., which would reduce the usability of the systems.

Generally, spaces in buildings have their specific image features. Therefore, using space images as space identification tags might be an alternative for indoor localization. Images could spend less expenditure for indoor localization, comparing with the previous localization technologies. On the one hand, images spend no direct cost; on the other hand, image retrieving with mobile devices, such as digital cameras and smart phones with cameras, is relatively easy and convenient. Few additional devices would be used for taking images to identify indoor locations.

Moreover, combining indoor localization system with the building information model (BIM) is necessary for building maintenance and operation usages. Not only because BIM is the state-of-the-art technology for construction industry, but also this facilitates the reuse of the design and construction information in the BIM model and increase the integration capability with other facility management information systems. Consequently, this study aims to implement the idea of using indoor space images as the space identification tags, so that users can detect the symbolic locations (not physical position) of spaces by image recognition technique. Moreover, by combining with the existing BIMs, the necessary space relative data for facility management can consistently be retrieved after the location detected.

In the following sections, the architecture of the prototype is addressed firstly. Secondly, the system design and implementation for the prototype are described to validate the technological feasibility of the proposed architecture. Subsequently, the system test and discussion including system localization capability and brief economic analysis are illustrated.

**BIM-VISION-BASED LOCALIZATION PROTOTYPE ARCHITECTURE**

To combine BIM data with space image information, the client-server architecture is referred for development of BIM-Vision-based localization prototype. Figure 1 illustrates three main components schemed in the prototype, namely, (1) Spatial image database, (2) Spatial image management module, and (3) Vision-based recognition module.

The spatial image database is the space-related data collection providing the connections between the space relative data imported from the IFC (Industry Foundation Classes) files derived from the existing BIM model\textsuperscript{3} and the space feature image information retrieved form users. The spatial image management module running on Android platform, the operation system of mobile devices, provides functions to collect the space photo images in buildings, and bind the images with the space data in the spatial image database. Then, the vision-based localization module developed based on the D’fusion studio \textsuperscript{4} can identify the locations by recognizing the images in the vision captured with the camera on a mobile device and then retrieve the corresponding spatial data from the database.

**PROTOTYPE DESIGN AND IMPLEMENTATION**

Based on the proposed architecture in Figure 1, a prototype was developed following the system design and implementation process.

**System design**

The details of the three primary components in the prototype are described as in this section.

**Spatial image database**

The spatial image database is the storage of the relationships of the space and image data, where the space data was imported from the BIM model and the image data was collected by the system users. With this database, once the space image was recognized, the system can retrieve the space relative information via the relationships. The entity-relationship model of the database was schemed as Figure 2 shows. The relationship between “Space” and “Image” entities is the key connection for space localization function. The space relative information, such as structural elements, facilities elements, etc., could be optionally added to the database for facility management utilizations.

The Figure 2 shows illustrates the relationships between spaces and their corresponding objects in the IFC file derived from the BIM model. The space information including the space name, space’s GID (Global ID) and the Cartesian point of space, are imported to the “Space” table in the database; the additional elements’ information, such as windows, structural elements, facilities, and the spaces their belong to can be also optionally imported to the corresponding tables.
Spatial image management module

The spatial image management module is a functional module designed for space images collection using mobile devices. Since the collected images should provide enough features for space identification, this study proposed the concept of “space recognition image set” to increase the robustness of indoor localization (shown in Figure 4). Instead of using single image for recognizing a space, an image set including three space photos taken from three different view angles is collected. According to the multi feature images in a space recognition image set, the system can identify a space with more features which would prevent the identification fail due to a lack-of-feature space image. In our cases, bringing more photos to a space image recognition set increases the probability of successful space identification; however, it also increases the calculation loading of the program running on mobile devices. According to the computation capability of current mobile computer devices, three images in a space recognition image set could be a proper tradeoff.

Accordingly, the sequence diagram of the spatial image management module was schemed to assist users create space recognition image sets of all building spaces. In Figure 5, once the space recognition image set is created, users need to pair it with space name instantly on the mobile device. Once the pairing relationship of the space recognition image set and space was identified by users, the images and relationship information will be transferred to the spatial image database via 3G or Wi-Fi network.

Vision-based recognition module

The vision-based recognition module is the kernel of the prototype system running on the mobile computer device which takes the responsibility to identify the space using the created space recognition image sets. Image recognition and space fitness (SF) cal-
calculation are two functions of this module. Figure 6 shows the identification procedure of this module. Users need panoraming of the space with camera-embed mobile computer device, and the functional module will recognize each image frame in the captured vision. Once a feature image in the space recognition image sets is recognized, the space fitness value \((SF)\) corresponding to the space \(i\) will be calculated with Eq. (1).

\[
SF_i = \frac{NRI_i}{3} \times 33.3\%
\]

(1)

where \(SF_i (0 \leq SF_i \leq 100\%)\) is the space fitness value of the recognized space \(i\). \(NRI_i (0 \leq NRI_i \leq 3)\) is the number of recognized images of the space recognition image set of space \(i\).

As the panoraming is finished, the space would be identified according to the space recognition image set with the highest \(SF\) value, and then the corresponding space relative information could be retrieved via the identified space ID from the spatial image database.

**System Implementation**

According to the system design results, three primary functional modules were implemented on Microsoft® windows and Google android operation systems. Figure 7 shows the implementation of spatial image database on MySQL database server running on the Microsoft® windows 7 operation system. To import data from BIM model to the spatial image database, this study adopted the IFC Parser 7 to transfer the IFC files, exported from BIM models, to the database semi-automatically.

Meanwhile, an App (Application) including spatial image management module and vision-based recognition module was implemented running on the android smart phone. Figure 8 shows the space photographing function to create a recognition image set of a space, where an instruction will appear guiding users to take three images to generate a space recognition image set (step 1~2 in Figure8). Once the image set is created, it should be paired with its corresponding space name (step 3 in Figure 8), so that the recognition image set can be used as the space identification tags in the system.

Finally, the vision-based recognition module was implemented with the D’fusion studio which is a commercial Augmented Reality (AR) development tool. By using the image recognition components of D’fusion studio’s library to recognize images in the visions according to the pre-created space recognition image sets. Figure 9 shows the image recognition procedure for indoor localization. The recognized space information will be revealed on the screen in real-time. Users can easily get the space information by panoraming in the space with the camera on the smart phone.
SYSTEM TEST AND DISCUSSION

System Test
To understand the identification capability, a preliminary experiment including 61 test spaces was finished using the developed prototype system. Since the space identification capability differs by space environments, we classified the test cases into 8 space categories as shown in Table 1. No case was identified successfully in the not-decorated room and similarly-decorated rooms. This is an obvious result due to the limitation of image recognition; i.e. the rooms with blank walls, similar layouts and decorations provide either insufficient or similar image features so that image recognition program could not identify them accurately. In the other cases, 60% ~ 85% spaces can be successfully identified with 60% to 80% SF values, and the failure cases, except not-decorated room and similarly-decorated rooms, the prototype can all be identified successfully by recreation their space recognition image sets.

Table 1. Prototype Test result summary table

<table>
<thead>
<tr>
<th>Space type</th>
<th>Space Samples</th>
<th>Space identified</th>
<th>Average SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not-decorated room</td>
<td>10</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Decorated room (similar)</td>
<td>10</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Decorated room (not-similar)</td>
<td>10</td>
<td>8</td>
<td>75.9%</td>
</tr>
<tr>
<td>Corridor</td>
<td>10</td>
<td>7</td>
<td>66%</td>
</tr>
<tr>
<td>Atrial</td>
<td>6</td>
<td>5</td>
<td>71.5%</td>
</tr>
<tr>
<td>Hall</td>
<td>5</td>
<td>4</td>
<td>72.6%</td>
</tr>
<tr>
<td>Outbuilding</td>
<td>5</td>
<td>4</td>
<td>79.2%</td>
</tr>
<tr>
<td>Independent open space</td>
<td>5</td>
<td>3</td>
<td>59.4%</td>
</tr>
</tbody>
</table>

Discussion
According to the test results, following discussions are described:

1. Using space images as location identification tags have the potential capability to be the alternative method for indoor localization (space detection). However, to make up the insufficiency resulted from the limitation of image recognition, the Quick Response (QR) code, the trademark for a type of two-dimensional code, could be used additionally to be the "Artificial" space recognition image set. That is, QR codes could be attached in the non-decorated and similarly-decorated spaces to indicate the space names so that the location can then be accurately identified by the image recognition technology with the same mobile devices.

2. The feature richness of the space images determines the localization accuracy. If necessary, more than three images could be added to the space recognition image set to provide more space features. However, this would increase the calculation loading for image recognition on the mobile devices. Besides, the localization capability using image recognition technology would be influenced by some environmental conditions, such as lights and variability of spaces.

3. Using images for indoor localization could be relatively inexpensive than other indoor localization technologies. A rough economic analysis for three indoor localization/positioning technologies, namely, (1) RFID-based indoor localization method1-8, (2) wireless sensor network indoor positioning system9,10 and (3) image-based indoor localization (this study), was fulfilled to understand the economic capabilities of each technologies. The total costs including the fixed and variable costs of three applications were estimated according to the proposed models in the literatures. Figure 10 illustrates the relationship between the total costs and application area in buildings for each alternative. For RFID-based and wireless sensor network positioning technologies, the total costs increase more rapidly by application area than image-based indoor localization method. According to the rough estimation in Figure 10, as the application area is less than 10870 m², wireless sensor network positioning method would be the economic choice, while the image-based localization method should be more economical for large area applications.

4. Combining Indoor localization system with BIM is a proper strategy to improve the additional-value of indoor localization system. However, the relationship between entities and spaces in BIM models should be created preliminarily in the design phase.
CONCLUSION

Based on the idea of using space images as the indoor space identification tags, this study adopted the IFC File Analyzer7 and D’fusion studio development tools to facilitate the BIM-Vision-based indoor localization prototype. The spatial data in the existing BIM model can be transferred to the prototype via IFC files. Accordingly, the space information of system can be synchronized with the BIM model and the space relative information could also be imported to the system for more facility management functions in the future.

The proposed prototype system was tested to be a potential alternative method of indoor localization because the identification accuracy (60% ~ 80%) of the system is acceptable (for a prototype), and the economic analysis revealed the image-based indoor localization method could be an economic alternative for large scale buildings.

However, the capability of image recognition technology limits the application of the prototype. For now, the prototype has no function for the spaces with few or similar features, such as non-decoration rooms and similar-layout/decoration spaces. Therefore, the QR code is the alternative way to make up this functional gap for image-recognition-based localization technology.

Summarily, the indoor localization method proposed in this study is functioned as a space detector. Lack of the positioning mechanism, the coordinate location can’t be provided by current application. However, combining with the Inertial Navigation System (INS), the advanced indoor positioning system could be implemented in the future.

References
Automated prediction of condition state rating in bridge inspection

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3 Associate Professor, Concordia University, Montreal, Canada
* Corresponding author (r_adhika@encs.concordia.ca)

Purpose
This paper presents a new automated method to predict condition state rating in bridge inspection. The method is designed to identify proper risk-based inspection interval by neural networks and image processing techniques.

Method
The surface defect considered in this research work is the loss of surface portion (scaling) of concrete due to freeze-thaw action based on Ontario Structure Inspection Manual (OSIM). Earlier, digital camera has been effectively used for identification of cracks in concrete bridge inspection. The research presented in this paper uses digital camera and artificial neural networks (ANN) for defects identification and rating purposes. The problem associated with scale calibration while zooming of the camera to capture the details of defects is solved either by known dimension of existing nearby elements of the bridge or via artificial objects with known dimensions in the picture frame. Determination of depth of defects, however, poses another challenge when 2D picture frames are used in this process. Red, green and blue (RGB) color profile is used to estimate the depth of defects. Various image processing techniques are used to extract the feature vectors to characterise and quantify defects. Subsequently, an ANN model is developed to predict the depth of defects based on 7 attributes obtained from the image processing. Condition state rating of scaling defects is then modelled using a developed back propagation neural network model (BPNN).

Results & Discussion
The developed model is capable of predicting condition state (CS) rating of scaling defects as light, medium, and severe with correlation coefficient (CR) of 99%. The proposed method is aimed to identify the proper risk-based bridge inspection interval which can significantly shorten the inspection interval and can assist in planning and executing necessary maintenance and rehabilitation work.

Keywords: bridge inspection, condition state rating, neural networks, image analysis

INTRODUCTION
Bridges built during the boom period of infrastructure construction in the sixties and seventies are still in operation today. In Canada, more than 40% of the bridges currently in use were built over 50 years ago. The situation is not different in rest of the world. In the the United States, there are 565 thousands bridges, and more than 70% of them were built prior to 1935. The aging bridges are in need of immediate upgrade or renewal. In many cases, maintenance and rehabilitation actions are driven by crisis or disasters when funds are limited. This approach is not suitable for bridge management when most of the infrastructure has reached the design service life. Therefore, Bridge Management System (BMS) is developed to help in planning maintenance and rehabilitation actions to avoid crisis based management. For example, PONTIS has become a national standard for bridge management which has been adopted by the departments of transportation (DOT) in more than 40 jurisdictions in the United States. However, the reliability of the predicted results of BMS is highly dependent of the quality of inspection data. Many of the bridges in U.S. are required to be inspected once in every two years.

Traditionally, inspections are based on visual observations which lack adequate quantitative data for bridge condition evaluation. Risk-based bridge maintenance strategies and optimal inspection intervals are needed for proper utilization of available fund to maintain proper safety level to bridge structures. This method needs to proper identification and quantification of defects to assist risk-based BMS. The focus of this research is to support the risk-based BMS by developing an automated damage prediction method by analyzing the surface defects of bridges and of condition rating of concrete bridges surface defects.

BACKGROUND
The I-35 W Mississippi River Bridge was inspected one year before the collapse in August 2007. The bridge was built in 1964 and rated 4 out of 9 which could be operated without load restrictions. The investigations imply that the condition of such deficient bridges in the country may be worse than what officials have predicted. This draws serious attention towards proper inspection strategies for efficient bridge management. In 1990 Hachem had used the sufficiency ratio as one of the scheduling inspec-
tion parameter to determine the inspection interval. Wirsching and Torng (1989) used reliability analysis to find the inspection intervals of marine structures. Liu and Frangopol pointed that the BMS software does not consider environmental factors, material prices, geographical factors, and design parameters. This leads to uncertainty about the result of BMS to determine schedule for maintenance and rehabilitation. Liu in 2008 studied 69 collapsed bridges in the U.S. after 1967. The data showed that more than 50% bridges were collapsed due to collisions and natural disasters. These phenomenons are difficult to capture and to incorporate into BMS to get better results. In the past, a wide range of construction materials had been used for bridge construction. Therefore, it is difficult to establish a common inspection interval for bridges. One way to tackle this problem is to revise the inspection frequency based on risk-based management strategies. Since bridge monitoring and inspection are expensive, there is a need for developing automated bridge inspection systems.

Currently, some bridges use electronic sensors to constantly monitor bridges condition. Bagchi et al. (2007) developed a model for damage detection based on vibration of structures. Close-range photogrammetric and Non-Destructive Test (NDT) are widely being used in bridge monitoring and evaluation. In 1849, Laussedat first utilized terrestrial photographs to compile maps and later was recognized as the “father of photogrammetry”. Photogrammetry has been successfully used in identification of bridge length, width, lateral and vertical clearance and also documentation of historical monuments. An automatic bridge condition evaluation system based on LiDAR (Light Detection and Ranging) is developed by Liu. The above methods use advanced tools and sensors and may be applicable for major rehabilitation works. There is a need to develop a procedure which can accelerate the primary inspection process and enhance the output of existing BMS. Existing BMS uses experts for condition rating based on inspection report. Abudayeh et al. 2004 have proposed a framework for automated bridge imaging system which stores different surface defects, but the condition rating is assigned by expert through viewing the defects on monitors. Hence, an automation condition rating system needs to be developed that can be connected with any BMS database. In this paper, for automation, ANN has been used for prediction of condition rating based on analysis of digital photographs. Moselhi and Shehab-Eldeen (2000) used image processing and neural networks to automatically detect and classify defects in sewer pipes. As reported by authors, the accuracy rate of proposed algorithm is 98.2%. Khan et al. (2010) also used neural networks to analyze structural behavior of sewer pipes in terms of variation of condition rating. The reported success rate was 92.3%.

**METHODOLOGY**

In the 2011 Annual report of the office of the Auditor General of Ontario, a risk-based approach for monitoring the inspection for infrastructure has been recommended. The approach requires following up any unusual changes in a bridge’s condition since the previous inspection and identification of high-risk bridges. Once maintenance is performed, then risk and age associated with the bridge also change. This paper does not discuss the risk-based ranking of bridges, but recognizes that the risk of bridges depends on unit cost of repair which is evaluated form quantity measurement of defects. An automated procedure is proposed for quantification of scaling the defects based on Ontario Structure Inspection Manual (OSIM) and condition state rating of bridge elements as shown in Fig. 1. This approach assumes no prior database information about bridge surface defects. The methodology consists of three major components: data acquisition, attributes extraction (image processing), and neural networks models. The following paragraphs describe each component in detail.

**Data Acquisition**

A commercially available SONY-DSC T5 digital camera of 5.1 mega pixels with optical zoom 3x has been used here for data collection of bridge surface defects. For surface defect identification, close-range photographs are required with proper focus on de-
tails of defects. However, just taking random photographs are not much of our interests. So, each photograph frames must include either natural or artificial targets for calibrating the scale. In general, natural targets can include structural details of beams, columns, parapet walls and railings, patches on concrete and steel surfaces, and nuts or bolts on girders. When there is insufficient natural targets, artificial targets are to be used. The artificial target used in the present research consists 5 cents coin placed in the vicinity of defects. Fig. 2 shows an example of artificial target placed in the picture frame.

Fig. 2. Use of Artificial Target for Scale Calibration

**Image Processing**

ImageJ, commercial software for image analysis, was used to extract feature vectors of defects attributes. The general methodology for feature extraction is shown in Fig. 3. Images are loaded to imageJ software and preprocessed using a series of steps to enhance the image for further processing. These enhancements include image smoothing, image sharpening, contrast modification, and histogram modification. The attributes of a feature vector considered in this work are area, perimeter, and the lengths of the major and axes, aspect ratio, roundness, and depth as shown in Fig. 3. The first six attributes are obtained by selecting the defects, and setting the scale in software to convert pixel value to actual measurement. But for the estimation of depth, a different approach that uses the RGB color profiles is required.

**Use of Low Pass Filter:** To reduce the effect of high frequency components, low pass filter such as, Gaussian Blur can be used. In this work, the similar effect is produced from line selection tool of ImageJ. The width of selection line has been magnified 150 times the default mode until the edge can be detected clearly (Fig. 4). The digital data are extracted in MATLAB and processed further to find the difference in average color intensity at desired locations.

**Relationship between the difference in intensity (DIB) and the depth of a crack:** The relationship between DIB and depth of defects is developed by taking actual field measurements. The resultant approximation can be expressed by

\[ t_d = K \times \text{DIB} \]

Where, \( t_d \) the depth of a defect in mm, and \( K \) is the slope of the line plotted in Fig. 5. The value of \( K \) is obtained by taking the first derivative of equation (1) which is found to be 1.0253. The result shows that depth prediction error varies from 5 to 15% as compared to actual measurement depending on the presence of dirt in defected area, wet surface or exposed reinforcements. In many cases, the estimated depth is highly dependent on the color intensity at the detected edge.

**BPNN Models**

A back propagation neural networks (BPNN) has been developed to model the relationship between the depth and condition rating of structural elements. The following two models have been constructed: Model ‘a’ to predict depth, and Model ‘b’ to predict condition rating, as discussed above. While both models are similar, Model ‘b’ contains an additional attribute of depth input variable in the data pattern to...
predict condition state (CS) rating of defects in bridge elements based on the severity of observed defects. The neural networks modeling process is shown in Fig. 6. The above models have been implemented using a commercial software namely Neuroshell 2\textsuperscript{21}.

![Fig.5: Relation between different in Intensity and Depth in mm](image)

### Table 1. Description of Condition State Rating

<table>
<thead>
<tr>
<th>Defects</th>
<th>Light (1)</th>
<th>Medium (2)</th>
<th>Severe (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaling</td>
<td>Local Flaking/Loss of Surface Portion of Concrete or Mortar due to Freeze or Thaw</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Up to 5mm Depth</td>
<td>6-10 mm Depth</td>
<td>&gt; 10mm Depth</td>
</tr>
</tbody>
</table>

### Data Collection and Pre-processing

Data are collected from bridges located in Montreal, Quebec, Canada. Digital photographs are taken from close range so that the defects are magnified. Condition rating grades are adopted from Ontario Structure Inspection Manual (OSIM)\textsuperscript{23} where condition state rating of 1 indicates light damage and 3 indicates severe damage. Table 1 summarizes the condition state rating grades mentioned in OSIM.

### Equation (2)

\[
X_{ni} = \frac{(X_i - X_{\text{min}})}{(X_{\text{max}} - X_{\text{min}})}
\]

where \(X_{ni}\) is the normalized value of \(X_i\); \(X_i\) is the \(i\)th value of a data series \(X\) representing the raw data; \(X_{\text{min}}\) is the minimum value of \(X\) in the sample set; and \(X_{\text{max}}\) is the maximum value of \(X\) in the sample set.

### Training of the BPNN

The network architecture is adopted from Neuroshell 2, 1996\textsuperscript{21} online documentation manual shown in Fig. 7. The network consists of five layers of neurons with one input layer (the number of input neurons are equal to number of attributes in each pattern), 3 hidden layers, and one output layer (the number of output neuron is one). A total of 19 data patterns have been prepared using the image analysis process which consists of 60% training sets, 20% testing sets, and 20% validation sets. Validation data set is also called the production set. The production set of data, which is not presented to the network during training, is later used to validate the model.

![Fig.7. Architecture of BPNN (Source: Neuroshell 2)](image)

### Table 2. Performance of Model-a

<table>
<thead>
<tr>
<th>Patterns processed</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.7024</td>
</tr>
<tr>
<td>(r) squared</td>
<td>0.7990</td>
</tr>
<tr>
<td>Mean squared error</td>
<td>0.028</td>
</tr>
<tr>
<td>Mean absolute error</td>
<td>0.147</td>
</tr>
<tr>
<td>Min. absolute error</td>
<td>0</td>
</tr>
<tr>
<td>Max. Absolute error</td>
<td>0.278</td>
</tr>
<tr>
<td>Correlation coefficient (r)</td>
<td>0.8939</td>
</tr>
</tbody>
</table>

### Table 3. Performance of Model-b

<table>
<thead>
<tr>
<th>Patterns processed</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>R squared</td>
<td>0.9807</td>
</tr>
<tr>
<td>(r) squared</td>
<td>0.9839</td>
</tr>
<tr>
<td>Mean squared error</td>
<td>0.003</td>
</tr>
<tr>
<td>Mean absolute error</td>
<td>0.032</td>
</tr>
<tr>
<td>Min. absolute error</td>
<td>0.000</td>
</tr>
<tr>
<td>Max. Absolute error</td>
<td>0.167</td>
</tr>
<tr>
<td>Correlation coefficient (r)</td>
<td>0.9919</td>
</tr>
</tbody>
</table>
RESULTS

The accuracy of the developed models is evaluated by applying validation sets data to the models. The validation sets of data are not exposed to the models during the training and testing of the models. After applying these sets of data, various statistical parameters are obtained to measure the accuracy of prediction of CS rating. The statistical features of the trained BPNN models are shown in Tables 2 and 3.

To measure the importance of an input variable in the neural networks output relative to the other input variables in the same network, a parameter called the contribution factor (CF) used in Neuroshell 2\(^{21}\). A large value of CF of a variable will indicate that it contributes more to the output than other input variables. However, a variable having a low value of CF does not mean that it shall be excluded from the model. The values of CF obtained for both the models are shown in Tables 4 and 5.

Table 4. Contribution Factors – (Model-a)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Parameter</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length of Major Axis</td>
<td>27.6%</td>
</tr>
<tr>
<td>2</td>
<td>Area</td>
<td>23.8%</td>
</tr>
<tr>
<td>3</td>
<td>Length of Minor Axis</td>
<td>19.6%</td>
</tr>
<tr>
<td>4</td>
<td>Aspect Ratio</td>
<td>12.2%</td>
</tr>
<tr>
<td>5</td>
<td>Perimeter</td>
<td>9.9%</td>
</tr>
<tr>
<td>6</td>
<td>Roundness</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

Table 5. Contribution Factors – (Model-b)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Parameter</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Depth</td>
<td>53%</td>
</tr>
<tr>
<td>2</td>
<td>Length of Minor Axis</td>
<td>9.6%</td>
</tr>
<tr>
<td>3</td>
<td>Aspect Ratio</td>
<td>8.8%</td>
</tr>
<tr>
<td>4</td>
<td>Roundness</td>
<td>7.6%</td>
</tr>
<tr>
<td>5</td>
<td>Length of Major Axis</td>
<td>7.2%</td>
</tr>
<tr>
<td>6</td>
<td>Perimeter</td>
<td>6.8%</td>
</tr>
<tr>
<td>7</td>
<td>Area</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

A comparison of the estimated output given by the BPNN model and the actual one for all data points of both models is presented in Fig 8. In Fig.9, the actual condition state is first obtained after evaluating the depth information from the first model and plotted against all the 19 patterns. Then Model ‘b’ is used to predict the condition state rating and validated by using the production sets. The results are summarized in Table 3.

APPLICATION AND LIMITATION OF THE DEVELOPED MODELS

The BPNN models developed here have designed by using Neuroshell 2 software. The trained model can be used to predict (a) the depth of cracks or defects on concrete bridge surfaces, and trained (b) the condition state rating of concrete bridge members. The trained models work in same way as experts classify and predict the attributes of defects based on their experience. The procedure can reduce the inspection time as the inspector needs only to take appropriate photographs, and analyze them using the proposed methods. With this application, the frequency of inspection can be increased without additional burden to client and hence could be possible to capture risk associated with environments and extreme loadings. Additionally, the efficiency of existing BMSs can be improved after integrating this model with any BMS like PONTIS. The risk associated with the changes in the condition of various elements or members in a bridge can be potentially assessed using the proposed methods which may help in making appropriate decisions for maintenance and rehabilitation actions. The proposed method will be helpful to track and record these events in proper time with less cost.

However, the developed models have their limitations. A close range digital photographs are required for defect identification which needs zooming capability of cameras. This method also requires a reference object of known dimension such as known dimension in the picture frame for calibrating the
scale. The changes in an attribute of a defect attribute depend upon location and weather conditions such as, temperature, moisture and lighting, and the developed models need corresponding reference conditions for calibration. More importantly, sufficient numbers of input data patterns are necessary to have better training and prediction capabilities. For better prediction capability, a robust database is required.

**CONCLUSION**

Inspection report is the major source of data for input to any BMS for maintenance and rehabilitation activities. Traditionally visual inspection, which is the primary method in use, is slow and expensive. In this research, machine vision techniques are used for automated prediction of condition rating and depth of defects. This approach utilizes digital photographs and neural networks to build data models which have many advantages as compared to traditional inspection. It uses non-contact techniques which is applicable to inspection in the areas which are not readily inaccessible. Also, it can quantify a large amount of geometric information in a short time with the help of digital image processing. Hence, it can be used as a tool for routine bridge inspection. There are several examples of photogrammetric identification and deformation measurement in bridge elements. Model ‘a’ demonstrates the prediction capability of depth of scaling defects whereas Model ‘b’ shows the prediction capability of condition state rating of bridge surface defects. The results show that the length of major axis has the highest contribution factor for depth prediction and the depth of defects has the highest CF for prediction of condition rating of bridge elements. The success rate in the first case is 89% and that in the second case is 99%. Since the proposed method is fast and less expensive, the frequency of inspection can be significantly increased to provide additional safety to bridges by recognizing the effect of extreme loads. Hence, it can be used as a tool for determination of risk-based inspection interval which requires proper quantification of bridge defects.

**References**

Digital Photogrametry in Investigation of Application membranes on the Surfaces of Cementitious Materials

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Purpose
The purpose of this work is to demonstrate usage of the photogrametry in construction, testing and monitoring of structures.

Method
The method of photogrametry is based on capturing digital shots of the cementitious surface covered with a membrane preventing water loss from concrete either by single shot or time-lapse method. By converting the pictures into gray scale and analyzing the brightness either of the whole surface or any differential area, we are able to calculate an evenness of the membrane application, a prediction of water loss from cementitious material, humidity underneath the membrane, and the areas of the structure most likely weakened due to excessive water loss.

Results & Discussion
We analyzed the effectiveness of concrete curing by application of a membrane (paraffin–based) on the surface of fresh concrete while studying loss of water depending on boundary conditions of the exposure to the ambient environment. The results in the picture help to refine the data and show this is a means of curing works up to 70%.

Keywords: automation, photogrametry, analysis, cementitious materials, water loss

INTRODUCTION
Dealing with concrete and cement based materials in construction, for sustainability of production and durability (linked to expenses), there exists a phenomenon of dependance of almost each performance on water content, expressed as water to cement ratio. There must not be neither too much nor too low water. This work is focused on practical application of the digital photogrametry in analysis of current state of concrete structures – mostly flat and exposed to severe boundary conditions.

Why water loss and what does affect?
As mentioned above, water loss determines process of hydration. To produce concrete of desired performances, there is some needed water content which must be provided. Its overrun leads to deterioration in quality. On the other hand, if there, in concrete, is too little water, hydration terminates and besides of that concrete undergoes undesired shrinkage what results in formation of cracks and this way shortening of durability due to ingress of harmful gasses etc. Both cases are wrong. A general approach is to produce concrete with as so low water content as possible with respect to fresh concrete properties. Therefore, loss of water from these concretes is rather serious issue.

Prevention
In general, operations, techniques and deliberate actions aimed at prevention of loss of water from concrete are together called curing. That must not been emphasized that through the years there have been developed many, more or less effective and sophisticated, curing methods. One of those which during last couple of years achieved the biggest success in construction, especially civil engineering, is membrane curing. This method, preferably used for large flat concrete structures, such as pavements and bridge decks, is based on spraying of curing solution, curing emulsion or suspension on the surface of finished concrete structure as soon as possible to avoid evaporation of water to the ambient environment to which the concrete surface is exposed5. After some (short) time, thin coating loses water and starts to protect the concrete. Until recently, there has been almost no chance to monitor a thickness, effectiveness or uniformity of this protective film. There were simple methods based on weighing of reference application area and this way checking the uniformity of application and calculating the result membrane thickness. This way, however, just application settings or adjustments were performed and checked. An evaluation of the uniformity and effectiveness of the applied film on the particular structure lacked. Usage of hereinunder described method in daily construction praxis can ensure instant evaluation quality of applicacion of the membrane and help to minimize drying shrinkage of concrete, eliminate the cracks formation and enhance the durability.

MEASUREMENT & AUTOMATION
Measurement involves common digital photogrametry technique. The concrete surface covered with liquid-applied curing membrane is photographed either once or continuously (depending on measurement purpose). From one shot (of certain
surface area), there can be calculated an uniformity of the application or if you want uniformity of the membrane thickness (and relating actual efficiency). From continuous shooting, of course, the uniformity of thickness but also time-depending efficiency of curing and prediction of water loss from concrete surface, as well as local volume changes or local stress can be predicted. The investigated parameter is the brightness of the picture. A fundamental principle is that any material’s light-reflection properties depend on the the surface texture and moisture. Generally, wet materials look darker as reflect less percentage of incident light. Based on this knowledge and purpose of the liquid-applied curing membranes (minimize water evaporation from concrete), we can conclude that darker areas in the picture are better cured then those which seem lighter.

Fig.1. Example of the laboratory sample of concrete covered with sprayed membrane with visible pattern of application (after software adjustment)

Process of automation the measurement consists of cyclicly repeated operations of taking picture of the concrete surface in certain position, than moving the camere above adjacent position making a stripe across the structure and then moving forward in direction of main dimension of the structure and, of course, repeating of described sequence. Captured pictures should overlap somehow in both directions.

By programming a macro (e.g. for Image-Pro software) looking up for the identical spots (e.g. based on aggregate grains on the surface or some cavities) a user is able to automatically composite all the taken photos making an overall picture of certain area. It could be convenient to set this area to be predetermined by position of future contraction joints or so.

Fig.2. Scheme of a frame holding and operating a camera above the premature concrete structure

By gathering the acquired data directly in PC or lap top and using the evaluation principles (described hereinafter) a contractor can instantly analyze the efficiency of the membrane curing and if needed, make provisions against rapid water loss from concrete.

Very important is to properly schedule the test according to boundary conditions of the environment (ambient temperature, relative humidity, wind velocity and sun radiation) determining intensity of water evaporation from the surface. There must be sufficient contrast between spots with evidently sufficient membrane thickness and evidently insufficient. With rising contrast level the dynamic range rises along. That is a key parameter in sense of accuracy. To achieve a higher level of accuracy, it is essential to take the pictures of the uniformly lit concrete surface. By lighting of the surface perpendicularly, the user may avoid distortion of the results by eventual shadows cast by some jogs.

It is recommended to expose in automatic or semi-automatic regimes (to medium - 18% grey) with matrix measurement. There are no requirements on maximum shutter speed, aperture and color management, however it is recommended to keep ISO sensitivity low as there is no relevant study on influence of the noise on the results.

**EVALUATION & INTERPRETATION**

The technique of evaluation of uniformity and/or efficiency of the liquid applied membrane is based on software adjustments of the shots and subsequent statistic analysis of the brightness channel. As a first step, the composite picture has to be cropped off the edges (outside the structure). If the investigated surface declines somehow from the camera sensor there must be performed correction of the perspective.

Fig.3. Scheme of taken pictures and overlapping areas
Since just brightness channel is investigated and with respect to size of the composite files, it is recommended to convert to grey scale.

It is obvious that the pictures lack contrast (has got low dynamic range) as can be seen in upper stripe in fig. 4. Even due to perpendicular lighting and automatic exposure, there are neither deep shadows nor highlights. The figure 4, in its middle stripe, shows the dynamic range of the picture in regard to absolute values 0-255, whereas the zero represents no brightness and with value 255 the 100 % brightness is associated. From this picture it can be seen that actual dynamic range is just some fraction of absolute dynamic range.

The figure 4 is prepared in a way, where the darkest (75 %) grey correspond to absolute value 64 and the brightest (25 %) grey corresponds to absolute brightness of 191. If subtract these two values (191-64) we will get 127 what is approximately half of the available dynamic range. The half dynamic range would carry twice higher uncertainty within brightness analysis. In general, an increase in uncertainty equals to multipie of reciprocal of the ratio of dynamic range of the picture to absolute dynamic range. For precisig of the analysis of the picture is essential to extend the dynamic range of the picture trying to meet the absolute dynamic range. In common softwares, it is possible using function “levels”. In this step, there is assigned the zero value (0 % brightness) to the darkest spot in the picture.

The brightness of the individual pixels in initial dynamic range are now (in adjusted) picture transformed into brightness in manually (or automatically) given range. The brightness analysis is further performed on adjusted picture. The very first step in analysis itself is to determine a frequency of the pixels of single brightness level in range of 0-255, which is graphically presented as common histogram (e.g. fig. 4). Along a horizontal axis, the brightness is to be set from 0 to 255. The vertical axis shows the relative frequency of occurrence of pixels carrying given brightness information. The relative frequency $P(b_i)$ in (%) is to be determined automatically according to formula 1, where $p(b=b_i)$ is a number of pixels in x direction and $p_y$ is a number of pixels in y direction.

$$P(b_i) = \frac{\sum_{b=0}^{255} p(b=b_i)}{p_x \cdot p_y} \cdot 100 \quad (\%) \quad (1)$$

The outcomes of the analysis are the statistic parameters of investigated data file (composite picture) to which the picture can be considered because during the exposure, there is assigned an individual value (from 0 to 255) of brightness to every single pixel according to efficiency of curing in that very spot. In this meaning the brightness is a stochastic variable. The main statistic parameter of the data file are an average value of the brightness $b_{\text{AVG}} (-)$, standard deviation $\sigma_b (-)$, file size = number of pixels and a number of the found brightness levels $\Sigma(b_i) (-)$. From the formula 2, there is to be derived the relative dynamic range $\text{DR}_R$ (%)

$$\text{DR}_R = \frac{\sum b_i}{255} \cdot 100 \quad (\%) \quad (2)$$

$\text{DR}_R$ provides information on a resolution or uncertainty of the measurement. The information on an average brightness of the picture $j$, $b_{\text{AVG},j}$ is given in scale 0-255 what is for obvious reasons impractical scale. Therefore, according to formula 3, it is transformed to an average brightness value $100b_{\text{AVG}}$ given in (%) of grey scale. The same approach is to be applied, according to formula 4, to an average value of the standard deviation $\sigma$.

$$100b_{\text{AVG}} = \frac{\sum_{j=1}^{n} b_{\text{AVG},j}}{n} \cdot 100 \quad (\%) \quad (3)$$

$$100\sigma = \frac{\sum_{j=1}^{n} \sigma_{b,j}}{n} \cdot 100 \quad (\%) \quad (4)$$

This way modified characteristics of the data file represent one sample (surface) exposed to ambient environment with certain combination of the boundary conditions. Coming out of display of the differential areas with absolute curing using membrane, i.e absolute black (100 % grey) and attempt to meet the absolute coverage of the sample (surface) with the (liquid applied) membrane, it is favourable to transpose the average brightness into an invert (formula 5). The average brightness is to be transposed to the
invert parameter which characterizes the data file in a sense of achievement of the idealized absolute curing (100%). It means, 100 % coverage of the surface with membrane and as a result – black (100% grey) on 100 % of the surface.

\[
\frac{1}{100} b_{AVG} = \frac{1}{n} \sum_{j=1}^{n} \left( 100 - \left( b_{AVG,j} \cdot \frac{100}{255} \right) \right) \quad \text{(5)}
\]

From now on just the individual samples (surfaces or their parts) are to be evaluated using the invert parameters. Then the average invert brightness of the sample may be understood as an average level of accomplishment the absolute curing or as an average level of the sample with absolute curing (by membrane). Therefore, if the average (invert) brightness \(100 b_{AVG}\) meets e.g. 75 % and the standard deviation \(\sigma_b\) is 10 %, then sample was cured on 75 % of the surface. Hence, the statistical file is large enough (in multiple of \(10^6\) pixels) it is reasonable to deal with dispersion \(\sigma_b^2\) or standard eviation \(\sigma_b\) of investigated brightness and therefore with the uniformity in thickness of applied membrane or process of application as such. For simplification, hereinafter just “uniformity of application” is being used. In terms of uniformity, the interesting areas are at the outer areas of the histogram. The left part was adjusted by defining a “black point”. If there are not any clear frequencies of high brightness at the left part, then the application was quite uniform. Acquired data on the average brightness \(100 b_{AVG}\) (%) and standard deviation \(100 \sigma_b\) (%) are used for determination of enlarged uncertainty (or data reliability) by cover coefficient \(k\). To a confidence probability 68,27 % corresponds \(k=1\), to 95,45 % corresponds \(k=2\) and to the confidence probability 99,73 % corresponds \(k=3\). In fig. 5 and in common practice, it is sufficient to use \(k=2\) by which it can be derived from formulas 6 and 7 an interval \(100 b_L - 100 b_U\) (%). With the confidence probability 95 %, there belong either the average brightness or assigned average area with absolute curing, to this interval.

\[
100 b_L = 100 b_{AVG} - \left( k \cdot 100 \sigma_b \right) \quad \text{(6)}
\]

\[
100 b_U = 100 b_{AVG} + \left( k \cdot 100 \sigma_b \right) \quad \text{(7)}
\]

From the average brightness \(100 b_{AVG}\) (%) and from standard deviation \(100 \sigma_b\) (%) at selected level \(\alpha=0,1\) (i.e. reliability \(1-\alpha = 0,9\) and number of datapoints \(m\) (multiple of \(10^5\)), the 5 % fractile \(Q_{0,05}\) of the brightness is derived following formula 9. The \(Q_{0,05}\) equals to lower tolerance interval \(b_{L,0,05}\) (%) which is defined as a subtraction of a degree of freedom \(x_{0,05}\) from the invert average brightness \(100 b_{AVG}\) (%). The degree of freedom is defined by formula 8 as a conjunction of factor of one-side tolerance interval \(K^d\) and the standard deviation \(\sigma_b\) of the brightness. The factor of one-side tolerance interval \(K\) on safety side, has been estimated (for number of datapoints \(10^5\)) as 1,700 (-).

\[
x_{0,05} = K \cdot \left( \frac{100 \sigma_b}{\alpha} \right) \quad \text{(8)}
\]

\[
Q_{0,05} = b_{L,0,05} = 100 b_{AVG} - x_{0,05} \quad \text{(9)}
\]

The lower tolerance interval or 5 % fractile represents the percentage of the invert brightness, in comparison to which 95 % of the pixels show higher invert brightness.

**EXPERIMENTAL STUDY**

This method was developed and used for assessment of uniformity of parafin emulsion application. The outcome is the average relative area with enlarged uncertainty (\(k=2\)) which is absolutely cured by applied parafin membrane. It can be identified with the average brightness \(100 b_{AVG}\) (%).

There was a goal to find out the most appropriate method of application of the parafin membrane onto concrete surface to make as most uniform membrane as possible. For application, there was used a mechanical sprayer. Varying parameters of the sprayer and spraying affected overall uniformity of the application.

\[
\text{Fig. 6. Relative area of absolutely cured concrete}
\]

The most appropriate parameters of application showed the uniformity around 80 %. In other words, around 80 % (with standard deviation cca 10 %) of the area was cured absolutely (fig. 6).
CONCLUSIONS

The technique of the digital photogrametry was developed and successfully used within design of application of the parafin membrane onto concrete samples for the tests of curing efficiency when exposed to harsh weather conditions. The method needs further precising of technique of picture capturing (shutter speed, distance, exposure) to attain the best possible result, mostly in meaning of the dynamic range. It is also planned to work out a database of the membrane thickness in certain age which could serve as a reference in analysis and classification of the particular spots in terms of sufficient or insufficient curing.

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A Plane Tracker for AEC-automation Applications

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Purpose We propose a new registration algorithm and computing framework, the keg tracker, for estimating a camera's position and orientation for a general class of mobile context-aware applications in architecture, engineering, and construction (AEC).

Method By studying two classic types of natural marker-based registration algorithms, homography-from-detection and homography-from-tracking, and overcoming their specific limitations of jitter and drift, our method applies two global constraints (geometric and appearance) to prevent tracking errors from propagating between consecutive frames.

Results & Discussion The proposed method is able to achieve an increase in both stability and accuracy, while being fast enough for real-time applications. Experiments on both synthesized and real world test cases demonstrate that our method is superior to existing state-of-the-art registration algorithms. The paper also explores several AEC-applications of our method in context-aware computing and desktop augmented reality.

Keywords: information technology, AR registration, tracking, context-aware computing

INTRODUCTION
The ability to recover a user’s pose (i.e., position and orientation within a certain coordinate system) is critical in many engineering domains such as Augmented Reality (AR), robotics, context-aware computing, and computer vision, addressed with different terminology. For simplicity, we will refer to all of these as the registration problem in this paper. Despite the rapid development of sensor technology—such as the global positioning system (GPS) and inertial measurement units (IMU), as well as angle sensors like the digital magnetic sensor, gyroscope, and accelerometer—this problem remains a challenge. A GPS signal is hardly available indoors, IMU suffers from the drifting effect, and a magnetic sensor can be hugely affected by the changing environment, especially in challenging environments such as construction sites with all kinds of machines moving around, needless to mention the sensor’s annoying jitter effect. To overcome these technical insufficiencies, especially for indoor environments, infrastructure-based technology has been studied, such as RFID-based indoor tracking and wireless local area network (WLAN)-based indoor positioning. Yet these technologies are either costly or sensitive to the environment, and lots of work has to be put into the system calibration stage. Further, these technologies’ general inability to recover a user’s orientation is troublesome for 3D visualization.

Following this intuition, this paper proposes a new visual registration method called KEG planar object tracker, which essentially recovers the pose of the user, i.e., camera, in real-time from a set of planar markers whose own poses are known, capturing the idea that our tracker is familiar enough with the environment so as to perform an estimation of position and orientation, just as humans do. Firstly, the state-of-the-art methods in visual registration will be briefly introduced. Then among these methods, two important types of planar marker-based algorithms are discussed. The section following that explains the main contribution of this paper—an efficient improvement based on the previous two classes of algorithm frameworks, leading to the KEG tracker. Afterwards, several experiments are shown to demonstrate the superiority, under different objective quality measures, of KEG tracker. Also, two novel AEC applications that deploy KEG tracking algorithm is introduced.

REVIEW OF PRIOR RELATED WORK
The visual registration problem is actively studied in the computer vision community, and several algorithms have been proposed to address it. Based on their different assumptions on the environment (i.e., the surrounding world where visual registration is going to be performed), these algorithms can be classified into two groups: known environment vs. unknown environment. The first group of algorithms is less computation-consuming and easier to design since the only unknown is the user’s pose. Because they have been well studied, and many related powerful algorithms have been proposed in the last
two decades, it’s more realistic to apply them for solving real-world engineering issues. Within this class of methods, they can be further categorized into two groups: planar environment vs. non-planar environment. The first group is again easier to design because of the simple assumption made regarding the environment—a planar structure with known visual features. And the second group is more often applied in a controlled environment with limited space, such as a small manufacturing workspace.

The authors choose to take advantage of plane-based methods since planar structures are abundant in buildings, construction sites, and other human-made environments where engineering operations are conducted, which makes this type of method very convenient to apply. In addition, a planar structure can simply be an image printed out on a piece of paper and attached to a wall/floor of a corridor, with nearly zero cost. All of those advantages make this method ideal for application, and merit its investigation.

Plane-based methods can be further classified based on different visual features they adopt: fiducial marker vs. natural marker.

A fiducial marker is composed of a set of visual features that are “easy to extract” and “provide reliable, easy to exploit measurements for the pose estimation.” Usually those features are a set of black and white patterns forming simple geometry by circles, straight lines, or sharp corners and edges. Well known fiducial markers include ARToolKit and the newly proposed AprilTag.

Distinct from a fiducial marker, a natural marker does not require special predefined visual features. Instead, it treats any visual features in the same way. In this sense, almost any common image, ranging from a natural view to a company logo, can immediately be used as a natural marker. This major difference makes it much easier and more natural to set up a natural marker than a fiducial one. Users do not need to separately design special markers; they can simply take advantage of any meaningful pictures related to the problem of interest.

In addition, one major downside to a fiducial marker lies in the fact that it usually depends on the four corner points or edges of the marker’s quadrangle to do further registration estimation, which is the reason that fiducial marker-based methods will fail even if one corner is not within view. This disadvantage does not exist in natural marker-based methods; in fact natural markers do not even require a marker image to be rectangular.

Again, by the fundamental difference in the way they treat input images, natural marker-based methods form two groups: one group treats each input image independently, which is referred to as a detection-based method, such as; the other group needs two or more consecutive images as input, which is referred to as a tracking-based method, such as.

Since our proposed method evolves from both these algorithm groups, in the following sections we will explain in detail the process framework of each type of algorithms, as well as how it inspires and is jointly adapted to our proposed algorithm framework.

HOMOGRAPHY FROM DETECTION

In either fiducial marker-based or natural marker-based algorithms, the fundamental task is to find the transformation between the marker image plane and the current camera plane which contains that current image frame. Such a transformation, called as homography, maps points on the marker image to their corresponding points on the current image frame with the following equation:

\[ s[x', y', 1]^T = H[x, y, 1]^T \]

where \( H \) is a 3x3 matrix representing the homography, \( (x, y) \) and \( (x', y') \) are the corresponding points on the two images, and \( s \) is an unknown scaling parameter.

In fact, the general idea behind a plane-based registration algorithm is the fact that homography between two planes encodes the orientation and position information of one plane relative to another. From this perspective, registration is equivalent to finding the homography between the marker plane and the current camera plane. From projective geometry, one knows that with at least four point correspondences between two planes, their homography can be uniquely determined by solving a set of linear equations.

More complicated than fiducial marker-based algorithms, which take advantage of simple patterns to find correspondences and then estimate homography, natural marker-based algorithms require a lot more effort to solve a correspondence problem.

Fig. 1 shows the generic algorithm framework of the homography-from-detection type of methods. The gray components need be loaded or calculated once.
during a computation, while the white components need to be updated for each new frame. $H$ is the homography between the current frame and the marker image. $K$ is the camera calibration matrix storing the focal length and some other intrinsic parameters, which can be calibrated in advance. $R$ is the rotation matrix representing camera orientation, and $T$ is the translation vector representing the position of camera center. For each incoming image frame, the first step is to detect a set of keypoints. Also, at the very beginning, a fixed set of keypoints has to be detected on the marker image. Interest point detection algorithms are usually applied in this step.

The second step involves a matching problem, i.e. finding corresponding points between two sets of keypoints based on their local appearance. Among the state-of-the-art algorithms, the Scale Invariant Feature Transform (SIFT) algorithm is perhaps the most famous and widely used nowadays. Although the SIFT algorithm works very well under large variation of visual conditions, it is computation-consuming, which makes it impractical to be applied directly in real-time applications, such as a registration problem, even after applying lot of approximation to SIFT. FERNs, differs from SIFT by the requirement of an offline training stage. Only after a long period of training using the marker image can FERNs recognize different keypoints on that particular marker under different visual conditions. Although FERNs and other similar methods enjoy the high-speed advantage, their relatively low recognition rate make them less ideal in registration problem, as to be shown by our experiments.

As mentioned, since most of these matching algorithms exploit a local feature descriptor, i.e. using image intensity information to describe a keypoint within only a limited neighboring region centered at that keypoint, mismatch is inevitable. In order to avoid most of these false matches, a robust estimation algorithm, such as the famous RANdom Sample And Consensus (RANSAC) is usually employed to estimate the homography.

Once homography is found—that is, through matrix decomposition techniques the camera position, the translation vector $T$, and orientation—the rotation matrix $R$, can be calculated. In our algorithm, a simple yet effective method was adopted.

**Homography From Tracking**

As shown in Fig. 2 homography-from-tracking type of methods explore relations between consecutive frames. Since images of two such frames usually look very similar, correspondences needed for homography estimation can easily be maintained by tracking each keypoint around its local neighborhood. Thus this type of methods can circumvent the hardest matching problem, since in this framework, matching between the marker keypoint and the current keypoint to get correspondences is only needed at the very beginning; after that, keypoint correspondences are maintained by a tracking algorithm. In fact, there are two such tracking algorithms that play crucial roles in our proposed method: the Kanade-Lucas-Tomasi (KLT) feature tracker and Efficient Second-order Minimization (ESM) algorithm. The KLT tracker’s ultimate goal is to find the feature point displacement within two consecutive frames. It assumes that during these two frames, the local appearance of the feature point $x$ does not change, and that the displacement is small. Then in order to find the optimal displacement, the algorithm formulates a least square problem to achieve a fast solution. While KLT’s motion model being fairly simple, ESM uses the 2D homography as motion model, and uses second-order approximation of the image function, thus leading to a global refinement algorithm with a faster convergence rate.

**Global Geometric/Appearance Constraints**

The advantage of homography-from-detection methods lies in the fact that since they treat each image frame separately, as we have shown in Fig. 1, estimation can be totally wrong at one particular frame, and the following frames won’t be affected at all. However, the problem with methods such as SURF and FERNs is that, in order to speed up the time-consuming matching step in detection, lots of approximations are adapted. This makes the homography estimation very unstable, resulting in a very annoying jitter effect if adopted in AR applications, i.e. the augmented object appears to be shaking in the scene. In our experiments, even if the camera is fixed, the estimated camera position and orientation could have very large variance.
In a different approach, homography-from-tracking methods, such as ESM and KLT, compare the current frame with the previous one in order to track the change. Although they benefit from the relatively higher tracking speed that improves their frame rate, one critical problem of this group of methods is that every tracker suffers from the drifting effect, i.e. the updated position of the tracked point actually differs to some extent from its true new position, and will thus eventually fail. The drifting effect will lead to large error in homography estimation, since these drifting errors usually do not follow Gaussian distribution and shall be seen as systematic errors that are changing dynamically. Also, the greater the number of points failing to be tracked, the larger the variance that the estimated camera pose could have. Thus the augmented objects could be in a wrong position and shaking at the same time.

Our new framework (Fig. 3) integrates the homography-from-detection and homography-from-tracking frameworks, utilizing their strong points and circumventing their short-comings. In general, our framework starts by the original homography-from-detection framework. Once the marker image is detected along with a rough estimation of the homography, we immediately move into a coarse-to-fine framework. Only when the track is somehow lost will this procedure be repeated. Within our new framework, and firstly via the original tracking algorithm (KLT), a coarse homography could be found. Then, it would be refined by a global optimization algorithm (ESM). Finally the refined homography would be used to correct the positions of the set of points to be tracked in the next frame, which is inspired by our following analysis of the cause of the drifting effect.

**Drifting Effect Analysis**

After analyzing the drifting effect in homography-from-tracking methods, we found that it is actually an error accumulation issue. During the tracking between every two consecutive frames, the error introduced by any tracking algorithm is accumulated. After a while, this accumulation could directly lead to the tracking of a wrong local target or even to the failure of the tracker. After realizing this, one pertinent question to ask is: is there any way to correct the error before the next tracking is actually performed? It was found that this is possible, which led to the design of our proposed framework. To gain more understanding of the cause of the drifting effect, the detailed error analysis is shown, as follows.

Firstly, the error source of any tracking algorithm, such as KLT, can be seen as composed by the following terms:

$$\mathbf{x}_{new} = \mathbf{x}_{old} + \Delta \mathbf{x} + \varepsilon_d + \varepsilon_g$$

where $\mathbf{x}_{new}$ is the updated position estimated by KLT, $\mathbf{x}_{old}$ is the true original position, $\Delta \mathbf{x} = \mathbf{x}_{new} - \mathbf{x}_{old}$ is the true displacement, $\varepsilon_d$ is the systematic drifting error, and $\varepsilon_g$ is the rest of the error, which is assumed to follow some Gaussian distribution. Here, $\Delta \mathbf{x}$ is caused by physical movement between the camera and the scene, $\varepsilon_d$ is mainly caused by camera CCD sensor noise, and $\varepsilon_g$ is usually caused by the tracking algorithm and other complicated reasons, such as the fact that KLT will be affected a lot when the camera is moving too fast, which leads to motion blur and thus violates KLT’s underlying assumptions.

The second step of homography-from-tracking methods applies RANSAC to estimate $H_{coarse}$ from the array of tracked points $\{\mathbf{x}_{new}\}$ and their corresponding points on marker image. However, even though RANSAC can eliminate a lot of outliers if the absolute value of error $|\varepsilon_d + \varepsilon_g|$ exceeds some threshold, and further, can eliminate the Gaussian error $\varepsilon_g$ by a final least-square estimation on the outlier-free subset of correspondent points, there still remains a part of systematic drifting error $\varepsilon_d$ not handled and thus propagated into $H_{coarse}$. In the homography-from-tracking framework, neither $\varepsilon_d$ nor $\varepsilon_g$ are corrected during the update step, so these errors are accumulated, which can cause a large drift even after a few frames of tracking.

**Error Correction by Global Constraints**

One natural way to reduce the effect of $\varepsilon_d$ is to apply the global appearance constraint, as shown in Fig. 3, which essentially means that the original
marker image should look the same as the image rectified from the current frame by estimated homography $H$. Before this constraint, all of the information the KLT tracker used is local, while $\varepsilon_j$ is systematic, therefore a global optimization based on the whole marker image will theoretically eliminate all the systematic error and $H_{\text{coarse}}$ can serve as a good optimization starting point. After the drifting error is eliminated when estimating the refined homography $H_{\text{refined}}$, we can easily correct tracking errors and update keypoint positions to be filled into the next tracking iteration by the homography mapping:

$$x_{\text{new}} = H_{\text{refined}} \cdot x_{\text{ref}} \quad (2)$$

where $x_{\text{ref}}$ is a keypoint's position on the original marker image; we refer to this as applying the global geometric constraint (for it relies on the prior knowledge that all keypoints lie in the same plane). Since the estimated $H_{\text{refined}}$ is already theoretically error-free, updating using the above equation (2) instead of equation (1) prevents tracking error from propagating into the tracking of the next frame, and thus increases the tracking stability. Besides the improvement in accuracy, our algorithm also enjoys an increase in tracking speed. Because we have a global refinement step, we do not require the local tracking algorithm such as KLT to be very accurate by reducing the number of iterations of KLT algorithms that result in larger error $|\varepsilon_j + \varepsilon_g|$. Since the direct result of KLT is just a coarse homography serving as an ESM optimization starting point, a certain amount of error can be tolerated and will be theoretically eliminated after global refinement (ESM). Similarly, since the time complexity of a local tracking algorithm such as KLT is usually positively correlated to the number of points to be tracked, we can decrease the number of keypoints to be tracked. We refer to our method as the KEG (KLT Enhanced by Global constraints) tracker, and the complete algorithm framework is described in Algorithm 1. It’s worth noting that KLT, ESM, and RANSAC, as well as the initial detection method (AprilTag/SURF), are replaceable components in our approach. This makes our method very flexible and easy to be extended by new algorithms (as long as they serve the same purpose). We will offer detailed comparisons in next section showing that, even though our framework involves more steps, its performance in accuracy, stability, and speed is increased as compared to the state-of-the-art algorithms.

**Algorithm 1: KEG algorithm framework.**

1. Detect N keypoints $\{x_{\text{ref}}\}$ on marker image $T$.
2. Apply Fiducial Marker method (AprilTag) or Homography-from-detection algorithm (SIFT), try to find the marker image and its corresponding homography $H_{\text{coarse}}$. If found, go to step 6; otherwise, re-do step 2.
3. Take a new incoming frame $I_{\text{new}}$, the last frame $I_{\text{old}}$, and the old keypoints’ positions $\{x_{\text{old}}\}$, perform local tracking (KLT) and output new keypoints’ positions $\{x_{\text{new}}\}$.
4. Perform robust estimation (RANSAC) on correspondent keypoint array $\{x_{\text{ref}}\}$ and $\{x_{\text{new}}\}$, then output $H_{\text{coarse}}$.
5. Apply global appearance constraint by ESM and output $H_{\text{refined}}$.
6. Validate $H_{\text{refined}}$ by similarity (zero-mean normalized cross-correlation, equation (3)) threshold. If valid, $H_{\text{refined}}$ can be output for homography decomposition; otherwise, meaning loss-of-track, go to step 2.
7. Update positions of keypoints $\{x_{\text{new}}\}$ by equation (2).
8. Replace $I_{\text{old}}$ with $I_{\text{new}}$. Replace $\{x_{\text{old}}\}$ with $\{x_{\text{new}}\}$. Go to step 3.

**EXPERIMENTAL RESULTS**

In order to validate our method and compare it to state-of-the-art algorithms, we did several experiments on both real-world and synthesized video sequences (in which we knew the ground-truth of the camera pose). Experiments were all conducted on a desktop computer with an eight-core 2.8 GHz Intel Core i7 CPU and similar performances were achieve on lower end computers. Also, all of the video sequences have a frame size of 640x480, which is the commonly adopted size of commercial webcams.

In all of the test cases to be shown in the following, for the purpose of showing the necessity of the three core components in KEG—local tracker (K-step), global refinement (E-step), and error correction (G-step)—and proving its superiority to state-of-the-art methods, we ran 7 different algorithms over those test cases:

1. KEG with AprilTag as initialization method (referred to as A+KEG).
2. No global appearance constraints applied; others are the same as 1 (A+K G).
3. No global geometric constraints applied; others are the same as 1 (A+KE).

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3. No global geometric constraints applied; others are the same as 1 (A+KE).
5. AprilTag, representing fiducial marker-based method (A).
6. AprilTag with global appearance constraints applied (A+E).
7. FERNs, representing homography-from-detection method (FERNs).

For the homography-from-detection component, we used our own C++ implementation of AprilTag, which originates from the java implementation by April Lab at the University of Michigan. For comparison with state-of-the-art homography-from-detection methods, we adopted the well-known and widely used Open-source Computer Vision (OpenCV) library implementation of the FERNs method. For the ESM method, we used the binary library provided by INRIA at http://esm.gforge.inria.fr/ESMdownloads.html.

We also looked at different performance metrics so as to have a comprehensive understanding of the performance of these algorithms:

**Duration**: The time to process each frame, reflecting the speed of the algorithm. This metric is crucial for real-time applications.

**NCC**: The zero-mean normalized cross-correlation between the marker image $I_1$ and the rectified image $I_2$ by $H_{\text{refined}}$, which can be calculated by:

\[
NCC(I_1, I_2) = \frac{1}{n} \sum_{x} \frac{[I_1(x) - m_1][I_2(x) - m_2]}{\sigma_1 \sigma_2}
\]

where $n$ is the total number of pixels of image $I_1$ or $I_2$, and $m_i$ and $\sigma_i$ are the mean value and standard deviation of intensity of image $I_i$. Obviously, if $I_1$ and $I_2$ are exactly the same, their NCC index should be one, and the larger their difference, the smaller the NCC index. This means NCC is a good similarity index. This index is also used in KEG to determine whether it loses track or not by a simple threshold of 0.5; if at any frame the NCC index is smaller than 0.5, it is regarded as a loss-of-track frame.

**LOT**: The total number of loss-of-track frames. This metric represents a registration algorithm’s stability to some extent.

**T-RMS/R-RMS**: The root mean square error between estimated camera position/orientation and ground truth. This metric represents the absolute accuracy of a registration algorithm, and is calculated by:

\[
T_{\text{RMS}} = \sqrt{\frac{1}{k} \sum_{i=1}^{k} ||T_i - \hat{T}_i||^2}, \quad R_{\text{RMS}} = \sqrt{\frac{1}{k} \sum_{i=1}^{k} ||E_i - \hat{E}_i||^2}
\]

where $k$ is the total number of frames of a test case, $T_i$ and $\hat{T}_i$ are the i-th frame’s ground truth and estimated position vector of dimension 3x1, and $E_i$ and $\hat{E}_i$ are the i-th frame’s ground truth and estimated Euler angle vector of dimension 3x1, respectively. Since these two indices require ground truth data, they are only examined for synthesized test cases.

**UOT**: We also propose this new index for estimating the extent of jitter effect of a registration algorithm, i.e. the unsmoothness-of-tracking, taking advantage of the NCC index by

\[
d_i = NCC_{i+1} - NCC_i, \quad \forall i = 1, 2, \ldots, k - 1,
\]

\[
UOT = \sqrt{\frac{1}{k-1} \sum_{i=1}^{k-1} (d_i - \mu)^2}, \quad \mu = \frac{1}{k-1} \sum_{i=1}^{k-1} d_i,
\]

where $NCC_i$ is the NCC index of the i-th frame, which essentially means that UOT index is the standard deviation of the difference between consecutive NCC indices. In MATLAB, this can be simply calculated by “std(diff(ncc)).” A stable registration algorithm should give a UOT index value as small as possible.

In all of the test cases, our marker image is composed of a 16 bits AprilTag of ID equal to zero and a natural image, the logo of University of Michigan that is rich in features. The synthesized test case is rendered in OpenGL, using our marker image and a static real-world image as background. And the real-world test case is recorded using a Logitech webcam.

Experiments shows that the average duration per frame of A+KEG is about 40 milliseconds, which is even faster than AprilTag (60~70 milliseconds). While other algorithms have very unstable processing time and are mostly slower than A+KEG, the only exception is A+KG, which is as expected since it has no global refinement step. These results prove that the KEG method does fit for real-time applications with process speed of 20 frames-per-second or faster.

Fig. 4 (a) shows that in most of the time, the NCC curve of A+KEG is the upper bound for the other algorithms, especially performing better than the state-of-the-art algorithm, FERNs. This means KEG tracker has the highest quality of tracking.

Fig. 4 (b) and (c) demonstrate that the A+KEG method has fewer loss-of-track frames, showing its ability to track longer, and lower UOT index, showing its smoothness in tracking—an important feature if applied in AR. Also A+KEG is more accurate, by giving less T-RMS/R-RMS errors in Fig. 4 (d) and (e).

Notice that here we assume the radius of our synthesized marker is 20 cm (which was the real size when it was printed out on an A4 sheet of paper in the real-world test cases). In this configuration, the KEG tracker’s maximum working distance can be as far as 3 meters, and its maximum working Euler angle can be about 85 degree offset from the marker image’s normal direction. If an even larger working distance is desirable, a higher resolution camera and bigger marker can be adopted.
APPLICATIONS

As noted in the Introduction, this algorithm has several potential applications in many different areas. One example application we implemented is context-aware computing. Indoor context-aware computing has been studied in AEC for its ability to speed up information delivery in many aspects, including construction site inspection/monitoring and facility management. Prior approaches for indoor ubiquitous tracking utilize an inertial measurement device, which suffers from its drifting effect. By Akula et al., a context-aware computing system integrated with both GPS and inertial measurement device is developed, requiring human intelligence to recognize certain predefined locations to manually correct the drifting error caused by the IMU.

In our application, manual error correction was naturally replaced by automated correction using the A+KEG method, as shown in Fig. 5 left. The green text shows that the algorithm successfully recognizes different locations by composing a natural photo (UM logo in this case) with different AprilTags. Once the inspector is within the effective range of the KEG marker image, the marker is automatically detected and then the inspector’s pose relative to the marker is continuously estimated.

Similar to Akula et al.’s method, both the location and orientation of these predefined markers in the global coordinate system are known and stored in a database. Therefore the inspector’s pose in the global coordinate system can be determined, as well. Benefitting from the KEG tracker, this application can provide automatic regional drifting error correction instead of manual point correction. This application can thus further facilitate information delivery on construction sites or in indoor building environments.

Another interesting application lies in tabletop augmented reality. Fig. 5 right shows a desktop environment AR showcase of a 3D building design. Since the KEG tracker has the ability to quickly detect and accurately maintain the tracking of a marker image without requiring that the marker image be fully in sight (as required by ARToolkit), it can easily be adapted into tabletop collaborative AR applications to support better interactive design demonstration or visual simulation for construction planning. Note that our KEG algorithm is open-source, so the C++ codes and demonstration videos for the above two applications could be found at our lab’s webpage (http://pathfinder.engin.umich.edu/).

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(a) Real-world case’s NCC curve. (b) Real-world case’s UOT index. (c) Real-world case’s LOT index. (d) Synthesized case’s T-RMS index. (e) Synthesized case’s R-RMS index.

Fig. 4. Experiment results of comparison between different algorithms.
CONCLUSIONS
After studying the two different types of natural marker-based registration algorithms and analyzing the cause of the drifting and jitter effects in both homography-from-tracking and homography-from-detection methods, a new natural marker-based registration algorithm, KEG tracker, is proposed, combining the advantages of those two, and circumventing their shortcomings. In theoretical analysis, we found that the drifting effect is an error that occurs because of an accumulation problem. We solved the problem by applying two global constraints: a geometric and appearance constraint. Experiments on both synthesized and real-world cases prove that the KEG method is fast enough for real-time applications, and also more accurate and stable than state-of-the-art algorithms such as FERNs and AprilTag, even when the marker image is partially occluded or viewed from very long distance. We also explored potential applications of the new tracker, such as context-aware computing, for replacing manually drifting error correction, and augmented reality for tabletop 3D visual simulation. In the future, one direction for further research is applying more object recognition techniques so that, without the need of composing a fiducial marker (AprilTag), our method could more naturally support multiple marker recognition and tracking. Extending our method to a 3D environment, such that no planar structure assumption is needed, could also be a very interesting research direction. In addition, specific AEC applications of the tracker can be explored, such as pose estimation for construction equipment.

References
Automated quality excellence evaluation

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Purpose We aim to enhance quality level organization by applying the EFQM (European Foundation for Quality Management) excellence model. We do this through analysis of current quality management trends, defining the EFQM-model structure and criteria (Figure 1) and the potential to introduce these with construction companies. We also propose an electronic manual and an automated evaluation system of the criteria and subcriteria of the EFQM-model by company management and also by external auditors.

Method Selected scientific methods of problem solution can be divided into two main groups: empirical and logical (scientific analysis and synthesis). The empirical method was applied to an electronic survey that aimed to determine knowledge of the EFQM-model and its practical use by companies operating in Slovakia. The logical method was utilized for the problem-solving analysis and synthesis. The method of scientific analysis was used to evaluate the current issue of the quality of the management level, EFQM-implementation in the construction sector, analysis of criteria and subcriteria of the EFQM-model, exploring the possibilities of applying the EFQM-model in a construction company, and an examination of existing systems of assessment under the EFQM-model. The scientific synthesis method was used during EFQM-model development and implementation, including the creation of an electronic manual, and during the process of automated evaluation system of construction company management quality.

Results & Discussion Our research work resulted in a methodology and an electronic manual allowing construction companies to effectively introduce and implement EFQM-model requirements in a relatively short period of time with the aim of constantly improving performance. The defined methodology suggests and explains the sequence of steps towards EFQM-model application; the electronic manual describes all of the EFQM-model subcriteria and provides concrete suggestions and solutions to meet them. The section of the manual dealing with the automated electronic system for construction companies was verified by a real company. Application of the methodology and manual enabled us in a short time to evaluate the company's quality of management and to identify opportunities for continuous quality improvement.

Fig. 1. EFQM Model Structure (last revision in year 2010)

Keywords: management & social issues, quality, automation, model, excellence, system, construction

INTRODUCTION

The EFQM excellence model is an European model based on Total Quality Management – TQM.1,2 It is designed for all organizations that are interested in continuous improvement and progress towards excellence. The main purpose of the EFQM model is self-assessment of the organization in order to achieve continuous improvement of quality. It helps identify strengths and opportunities for improvement and encourages solutions. It allows for an independent view on the organization and its functioning. The EFQM model is a basis for assessment and evaluation of a business aspiring to receive the European Quality Award (EQA), but also the Na-
tional Quality Award of the Slovak Republic. In order to win the EQA, the model must be applied for at least three years and yield the corresponding results. The EFQM model may be used in any business as well as any government organization (however, the Common Assessment Framework – the CAF model is specially designed for public administration).

**HISTORY AND STRUCTURE OF EFQM MODEL**

The EFQM model was created by the European Foundation for Quality Management (EFQM), which was founded in 1988. Its establishment involved fourteen large European corporations. The aim of the foundation was to create a model based on Total Quality Management (TQM) in order to achieve excellence in European companies and make them competitive in comparison with the U.S. and Japanese companies in the global market. Society-wide recognition of quality in the USA (Malcolm Baldridge National Quality Award) and Japan (Deming Application Prize) proved that the application of TQM models delivers measurable business results to organizations. The EFQM model first appeared in 1991 and it was called The European Model for Business Excellence. It was innovated in 1999 and it became more universal and applicable in a larger number of organizations. For public administration, the CAF (Common Assessment Framework) model was developed. It was launched in 2000 and revised in 2002.

The EFQM model is based on 9 criteria: leadership, policy and strategy, people, partnerships and resources, processes, customer results, people results and key performance results. The first 5 criteria are enablers (what the organization has got) and the remaining 4 criteria are results (what the organization achieves). All criteria are divided into sub-criteria; the total is 32 sub-criteria. The diagram of the model, together with score for each criterion is shown in Figure 1. The direction of arrows shows the dynamic nature of the model. Innovation and learning help improve enablers, which leads to improved results. This process is continuous. Criteria and sub-criteria of the model are very sophisticated and deal with all areas of the organization, even with the environment surrounding it. The model emphasizes the ethical principle crucial for those who are exceptional.

**SURVEY CONCERNING THE EFQM MODEL IMPLEMENTATION**

The survey concerning the EFQM model implementation has been carried out during three months in year 2011 by the form of electronic and anonymous questionnaire. There were surveyed 160 construction companies in Slovakia of all sizes. The questionnaire completed 36 of them.

The issues were identified about whether the model has been applied for excellence in the organization, the purpose of its application (or the reasons not to apply it), as well as interest of the construction company to introduce the EFQM model in the future.

Graphical interpretation of some of the responses is shown in Tables 1 and 2 and Figures 2 and 3.

**Table 1. Application of the EFQM model at present or in the past in surveyed companies**

<table>
<thead>
<tr>
<th>EFQM application at present or in past</th>
<th>Number of answers</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>NO</td>
<td>32</td>
<td>89</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 2. Interest of surveyed companies to implement EFQM model in future**

<table>
<thead>
<tr>
<th>Interest to implement EFQM model in future</th>
<th>Number of answers</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitely YES</td>
<td>13</td>
<td>36</td>
</tr>
<tr>
<td>Probably YES</td>
<td>14</td>
<td>39</td>
</tr>
<tr>
<td>Rather NOT</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Certainly NOT</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>100</td>
</tr>
</tbody>
</table>

The results obtained by survey shows that the EFQM excellence model and its application in
practice in Slovakia are still relatively new, unexplored issues. Most companies do not exclude its application in the future, but they need much more necessary information about this model and effective training process. The solutions contained at this contribution can be helpful for the performance of the EFQM model to organizations, which have aims to continually improve their quality management level and implement maximum positive effects in future activities.

**PROBLEMS AND AREAS FOR IMPROVEMENT REGARDING THE EFQM MODEL APPLICATION IN CONSTRUCTION ORGANIZATIONS**

The study the EFQM model through consultations with trainers in the area of Quality Management and our own knowledge concerning this area of interest made us aware of areas for improvement and problems currently faced by Slovak companies striving for excellence when implementing the EFQM model. Application of the EFQM model in Slovak organizations is currently not a very frequent activity. Although the model seems simple, its application is a complex process in terms of time and resources. The EFQM model can be described as a higher form of quality management in organizations. It is starting to be implemented mostly by organizations, which have successfully passed the introduction and certification of the Quality Management System (QMS) according to ISO 9001 and look for ways to further improve the quality of their products. However, the management in most organizations fails to realize that this approach to improving quality is not as simple as it seems at the first sight. Although the nine main criteria of the EFQM seem like they were encountered when building the QMS, the EFQM model contains a series of sub-criteria (32), which require a very detailed description of the functioning of the organization and many of the sub-criteria are often misunderstood by the management. Thus, the enthusiasm with which the management welcomes the introduction of the EFQM model begins to fade when the model is implemented in practice. A deeper study of the EFQM model makes directors come to conclusion that the whole process is too bureaucratic. Organizations often meet the EFQM requirements, but fail to record their results sufficiently and as required. When aspiring to the National Quality Award of the Slovak Republic or the European Quality Award, the company has to prepare a self-assessment report according criteria of the EFQM model, on the basis of which it is assessed. The preparation of the self-assessment report is an extremely complex and time-consuming process and requires involvement of key employees from all areas of business. Incorrect definition of processes and results in the self-assessment report may result in a low score of an otherwise successful organization from the professional EFQM auditors. This leads to disappointment, conflicts and rejection of the whole process.

The path towards excellence according to the EFQM model is a long-term process that must be upheld by the whole business from the top management to the last employee. If only the top management desires the introduction of the EFQM model and then delegates the application duties to employees – failing to properly explain its effects – it encounters resistance and the process is doomed.

The current competitive environment in the global marketplace requires organizations to continuously improve quality. This applies not only to products, but also to processes and management. Today, it is often not enough to satisfy customer needs, but it is necessary to exceed them. This requires excellence in organizations. One of the tools that can help organizations on their path of improving and achieving a lasting success is the EFQM excellence model understanding and effective implementation.

**METHODODOLOGY FOR THE EFQM MODEL APPLICATION IN ORGANIZATION**

During the research work at this area, we propose a methodology for application of the EFQM model, which is proposed especially to manufacturing organizations, which have developed and implemented Quality Management System (QMS) according to standards ISO 9001 and plan further development and improvement of the existing management system using the model EFQM. Steps of the methodology are illustrated in Figure 4.7

The methodology is designed in conjunction with manual and automated self-assessment system to enable the organization to apply the EFQM model in less time and evaluate their performance level and effectiveness by more transparent way. The methodology enables to get an idea of what is necessary to do in the process of EFQM model application. The actual implementation of the methodology and the manual is designed to avoid confusion and unnecessary complexity, what require starting again and resulting to time loss.

**Used scientific methods**

Selected scientific methods of problem solution can be divided into two main groups: empirical and logic (scientific analysis and synthesis). Empirical methods are applied to an electronic survey that aimed to determine knowledge of the EFQM model and its use in practice among organizations operating in
Slovakia. The logical method was utilized for the problem solving analysis and synthesis. Methods of scientific analysis was used to evaluate the current issue of Quality Management level and EFQM implementation in construction sector, analysis of criteria and sub criteria of the EFQM model, exploring the possibilities of applying the EFQM model in construction organizations and examination of existing systems of assessment under the EFQM model. Scientific synthesis method was used during the process of EFQM model development and implementation including the creation of electronic manual and during the process of automated evaluation system of construction company quality management level.

**Manual for the EFQM model implementation**

Electronic manual is designed on the basis of the EFQM model criteria and sub criteria requirements and helps to organization in a shorter time to understand and apply the EFQM model and evaluate their own performance and effectiveness. The structure of the proposed manual consists of three main parts:

- analysis of EFQM model requirements defined by criteria and sub criteria and determine the existing quality level of the organization and opportunities for improvement,
- self-assessment system of organization quality management level using the criteria and sub criteria of the EFQM model by electronic automated system.

The evaluation system of the EFQM model criteria

EFQM model consists of prediction and result parts. For each of them is in the manual suggested a specific method of evaluation. In this paper we provide an example evaluation of prediction part of the EFQM model.

In the process of self-assessment of the organization is for each of the manual requirements of prediction part of the EFQM model selected phase of applications based on the Deming cycle (Table 3) and the performance level (Table 4). The selected phase applications and performance levels are the basis for calculating the assessment for the achievement of the criterion and sub-criterion requirement. Position in the current phase of the application assumes management of the previous phases. If the company in meeting this requirement found for example in phase "act" with the degree to 0.5, the overall percentage achieved in meeting this

<table>
<thead>
<tr>
<th>Activity is:</th>
<th>Description</th>
<th>Evaluation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (planned)</td>
<td>Organization plans the activity to apply</td>
<td>10</td>
</tr>
<tr>
<td>D (done)</td>
<td>Activity is implemented</td>
<td>15</td>
</tr>
<tr>
<td>C (checked)</td>
<td>Organization checks the effects</td>
<td>20</td>
</tr>
<tr>
<td>A (acted)</td>
<td>In a case of positive effects activity is used in practice</td>
<td>25</td>
</tr>
<tr>
<td>B (benchmarked)</td>
<td>Organization compares the activity with best organization in market</td>
<td>30</td>
</tr>
</tbody>
</table>

**Fig.4. Steps to apply EFQM model in organization**

**Table.3. Evaluation of activity level application according to requirements of EFQM model sub-criterion in organization**
Table 4. Level of EFQM model sub-criterion fulfilling in a given phase of application

<table>
<thead>
<tr>
<th>Level of fulfilling</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>There is no evidence to fulfill the requirements</td>
</tr>
<tr>
<td>0.25</td>
<td>There exist indicators of compliance requirements</td>
</tr>
<tr>
<td>0.5</td>
<td>Partial evidence of requirement fulfilling</td>
</tr>
<tr>
<td>0.75</td>
<td>Significant evidence of requirement fulfilling</td>
</tr>
<tr>
<td>1</td>
<td>Clear evidence of requirement fulfilling</td>
</tr>
</tbody>
</table>

The resulting score for each criterion is the sum of achieved point value of its individual sub-criteria. The total achieved point value concerning the enablers is the sum of achieved points for criterion 1 to 5. (The maximum possible score can be 500 points (see enablers - Figure 1).

Electronic evaluation of the proposed solution

Electronic solution of proposed evaluation system is realized by using Microsoft Excel Program. The aim was to design and develop an automated system using computer technology, which would on the basis of defined requirements in electronic manual and in evaluation system allow easy, fast and comfortably realize evaluation of business performance and effectiveness, as well as clear and understandable display output of the evaluation process. Entering of inputs is handled through a questionnaire form, by selection of predefined options from "drop down menu" (dropdown list). The user does not perform any calculations, nor inscribe the input values. The results are updated immediately after any change in input data. The selected values the user can change at all time during the evaluation process. Sheets "enablers" and "results" clearly show achieved percentage scores for each sub-criteria and requirements, and from these values is automatically calculated score for sub-criteria, and all criteria of "enablers" and "results" sections. Changes of point values are automatically transferred to the sheet EFQM - assessment, in which is a graphical view of the structure of the EFQM model with the nine criteria and the corresponding percentage and scoring for each of them for the "enable" and "result" part and also total assessment of all criteria.

Application of the proposed methodology and manual into construction company

Application of the proposed methodology and the electronic manual was made for a construction company in Slovakia. During our cooperation we offered to the company basic training process concerning the EFQM model development and application and electronic manual for self-evaluation according to EFQM model criteria. Process of self-evaluation was realized using our software for automated evaluation quality management level in company according to EFQM model criteria. By application of the higher described methodology and electronic manual and the company during next 3 months showed improvement in all criteria of the EFQM model, (see Figure 5). Our cooperation will continue and we assume more dramatic improvements.
improvement next 1-2 years after implementation next actions especially in production process.

Fig.5. Evaluation of EFQM model in construction company before model application and after 3 months

Legend to Figure 5:
1 - Leadership
2 - Policy and strategy
3 - People (employees)
4 - Partnership and resources
5 - Processes, products and services
6 - Customer results
7 - People results
8 – Society results
9 – Key results

CONCLUSIONS

Model EFQM is useful to implement after development and implementation of Quality Management System (QMS) according to ISO 9001. QMS represents very good basis for application of higher quality management philosophy, like TQM, KAIZEN or model EFQM. Research work described at this contribution results in the form of its own methodology and electronic manual allows to construction organizations effectively introduce and implement EFQM model requirements to practice in a relatively short period of time with aim to constantly improvement its performance towards excellence.

Defined methodology suggests and explains the sequence of steps towards EFQM model applying the electronic manual describes all of EFQM model sub-criteria and provides concrete suggestions and solutions to meet them. The part of manual there is also automated electronic assessment system for construction organizations which was verified in real company. Application of the methodology and manual enables in a short time to evaluate company quality management level and to identify opportunities for continually quality improvement. Model EFQM is an effective tool for continual improvement of organization quality, which leads not only to higher level of quality, but also to customer satisfaction, success at national and world market and to increasing the culture of whole organization.

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References
Surveying of road slopes using mobile LiDAR

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* Corresponding author (higiniog@uvigo.es)

Purpose The slope of roads is one of the most important elements to be monitored to prevent landslides and ensure the safety of vehicles. This fact is particularly relevant in areas such as Galicia (Spain), where, due to its orography, slopes always are a relevant factor in road construction projects.

Method Typically, the slopes of the roads are visually monitored by road inspectors and only in case of important problems do they use measuring equipment (e.g. extensometer, inclinometer). The aim of this work is to introduce the routine use of mobile LiDAR systems for monitoring of slopes.

Results & Discussion A filter based on the returns of the laser shot is used to remove vegetation of the slope and work only with ground level information. An algorithm that compares the slope surface between two different inspection periods was developed. This algorithm extracts the systematic error due to GPS and can display variations of a few centimeters.

Keywords: automation, mobile LiDAR, road inspections, slope stability.

INTRODUCTION

The slopes are common in most roads, especially in high-capacity roads that run through mountainous terrain. The slopes of a region present different behavior, depending the nature of the rocks and geometry. This different behavior sometimes results in landslides, an important problem in the Galician roads, relief quite rugged and varied morphology. Landslides decrease the safety of the existing structures (i.e. bridges, tunnels, overpasses, underpasses) and in some cases directly block the road and become critical to produce car accidents.

Road slopes are typically monitored using geophysics and geodetic measuring methods. Geodetic measuring methods use total stations, levels and static LiDAR. Although these techniques appear accurate and reliable, their productivity is low and the labor costs associated are very important. In the recent years, mobile LiDAR applications have irrupted in the market 1,2. These systems combine DGPS positioning and LiDAR measuring. In addition, in the areas with poor satellite coverage, GPS is aided with inertial navigation systems and distance measuring indicators. The combination of DGPS, INS and DMI data is done in post-processing using Kalman filtering algorithms 3. Mobile LiDAR systems combine DGPS and LiDAR technology with RGB cameras to provide images of the scenes.

The productivity of mobile LiDAR systems is very high and they allow to measure between 100 – 200 km per journey with two surveyors (one driver and one LiDAR technician). Typically one day more is necessary to post-processing all the information and to obtain a geo-referenced point cloud and images. Mobile LiDAR systems are commonly installed in cars or vans, although they can also be arranged in boats or trains. The information generated is completely compatible with that obtained from airborne LiDAR or conventional surveying.

One of the main application fields of mobile LiDAR is in road inspections. They provide a complete geo-referenced point cloud of the road that can be used to analyze geometric parameters (i.e. vertical and horizontal clearance, slope geometry, tunnel profiles, road sections).

Although this technology appears very promising, the raw information must be processed and adapted to the normalized parameters required by the road managers. Nowadays, this step is done manually by human operators, increases the labor cost of the process and decrease the operability of the system.

In this work, a semi-automatic procedure to determine the geometric condition of road slopes is developed. The algorithms use the different echoes of the LiDAR to perform automatic vegetation filtering and geo-referenced points to avoid the GPS drifts between different surveying.

METHODOLOGY

Area of study

The slope selected for this study was situated in the Campus of Vigo University, close to the School of Telecommunications Engineering, which is situated on a hilly place at the outskirts of the city of Vigo. Figure 1 shows the situation of the slope (RGB and point cloud image). It presents some vegetation and a height difference of about 4.5 m.
Mobile LiDAR used in this study (Fig. 2) is the Optech Lynx system. The system integrates a navigation GPS/INS system from Applanix (POS 520 - 2 GPS antenna), 2 LiDAR scanners from Optech and 4 digital cameras from Jai (BB 500GE). The metric characteristics of the Lynx system are shown below:

- Maximun range: 200 m
- Range precision: 8 mm (1 σ)
- Absolute accuracy: 5 cm (1 σ)
- Scan frequency: 80 – 200 Hz
- Scanner field of view: 360°
- Laser measurement rate: 75 – 500 kHz

Mobile LiDAR survey began and finished with the acquisition of 5 min of GPS data in an area with small PDOP (high GPS precision). The complete time of the survey was 12 min. Scanner and photographic data are only taken while the van is moving to avoid the excess of data. The synchronization of the data from the different sensors of the mobile unit is achieved using the time stamp and the PPS of the GPS/INS system. A total of 120 million of geometric points were acquired during the survey. The survey was repeated one week after to establish a comparison between the two surveying of the slope. The aim of this work is to develop a methodology for exact slope inspection, so we prefer to adopt a slope without any appreciable geometric change.

The data processing is performed using Applanix POSPac and Dashmap software. The first one corrects the GPS information using a RINEX file from a base station. In addition, combines, using a Kalman filter, the data from the GPS with those obtained from the inertial navigation system (INS) and distance measurement indicator (DMI). The corrected trajectory file exhibits a precision higher than 2 cm in X Y and higher than 4 cm in Z.

Dashmap combines the range and angle information obtained from the Optech scanners with the trajectory information from PosPAC. The point cloud obtained will be managed using the QT Modeler software in addition to Matlab and AutoCAD software.

**Point cloud classification and filtering**

QT Modeler software (Applied Imagery) is used to the classification of the point cloud in function of the
number of returns, the light echoes that achieve the scanner detector (Figure 3). Optech system allows the detection of four echoes per geometric point.

![Fig.3. Point cloud classification by laser returns.](image)

Results show that vegetation areas depict typically two echoes (green points in Figure 3). The filter applied to automatically remove the vegetation consists on saving only the last return from the laser and remove the other returns. Figure 4 depicts the point cloud after the vegetation filtering. All the vegetation was perfectly removed. In addition, it was also necessary the removal of the tree trunks. This removal process was manually performed using the selection and cut toolbox of QT Modeler.

![Fig.4. Point cloud after vegetation filtering.](image)

Although the DGPS provides accurate positioning of the geo-referenced point cloud it is important to avoid possible GPS drifts to guarantee accurate measurements. In this work, some control points were used in both surveying to geo-reference both measurements in the same coordinate system (Figure 5). QT Modeler is used for the geo-referencing of the two surveying. Natural landmarks were used as control points to make the procedure more productive and easy to implement. Horizontal signage is very adequate for this purpose because the different light reflective provide clear marking points for the QT Modeler software.

![Fig.5. Control points used for the geo-referencing of the surveying.](image)

**RESULTS AND DISCUSSION**

Figure 6 shows the slope point cloud visualized using Matlab software. Previously, the LiDAR point cloud in las format is exported to ascii - xyz code and imported in Matlab.

![Fig.6. Point cloud visualization in Matlab software.](image)

The point clouds of both surveying were extracted one from each other to estimate the geometric differences between them and prevent the detection of possible landslides. In this case, there is no evidence of any damage in the slope (Figure 7). The result is quantified using a Normal distribution (Figure 8). The average of the Normal distribution is related with the accuracy of the method and the standard deviation with the precision, because the slope geometry remains stable during the both surveying. Accuracy of the procedure is 6.4 mm and precision (1σ) is 34 mm, which seems enough to study landslides in future researches. In addition the good fitting of the data to a Normal distribution also confirms the good quality of the results.
CONCLUSIONS

LiDAR mobile appears a productive surveying technology to obtain geometric characteristics in road inspection programs.

Filtering using LiDAR returns can automate the removal of vegetation and accelerate the processing of the point cloud.

Geo-referencing of point clouds from different surveying allows the comparison of the condition state of road slopes to determine the risks associated to their stability. Horizontal signage is used as landmarks and simplify the data acquisition process.

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Automated-driven concrete piling: Latest developments and experiments in Finland

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Purpose POHVAII is a large research project carried out in Finland between 2007 and 2011 to develop and test a new automated process for concrete driven piling. We also describe recent developments in the Finnish industry and evaluate the technology worldwide. Method Design, modeling, and an XML-based information transferring tool for structure designer (Tekla Structures) were newly developed, as well as a new 3-D guided piling machine using two GNSS antennas for positioning tasks and a graphical user-interface for the operator. Furthermore we developed a wireless monitoring system of environmental effects such as piling-related shakings and vibrations that could affect other nearby structures, and a system to measure real-time geotechnical bearing capacity of piles during hitting work. In the automated working process the main aim was to design, measure, save, transfer, and utilize all the different useful data using 3D-information models throughout the whole working process of the driven piling. Results & Discussion Several practical tests and experiments were carried out during the POHVAII-project. We will give a short introduction to the most important results of our 3D-guidance testing: the monitoring system for generated vibrations and the geotechnical bearing capacity measurements. We analyze the new automated piling process and compare it with the traditional process used in most developed countries. Great economical saving and environmental benefit potentials are reported and evaluated.

Keywords: 3D, automation, deep stabilization

INTRODUCTION

Background The traditional functional process of the column or deep stabilization method has been at the 2-D level. No 3-D data has been transferred from the planning stage to the control systems of deep stabilization machines. The driver has operated in accordance with the site markings and must keep a record of the columns made, mostly to facilitate his own work. After every three to five column stabilizations on average, the deep stabilization machine must be brought close to the tank car for filling of the binder tank. During working, the measuring sticks do not remain in place and the location of the column already pile-driven into the muddy terrain is not always easy to find. Reliable documentation is required so that each column point located in the field can be stabilized in accordance with the plan. This is not necessarily the case with the traditional process.

Also the traditional process functions on the so-called "constant binder feed principle", which wastes valuable binder and at the same time increases stabilization work consumption and costs. Unlike the current solution, the measurement of the quantity of the binder would be located as close as possible from the feed and mixer head, which would enable the control of accurate and real-time binder flow as a function of mixing depth. In addition to depth-oriented control, documentation concerning the success of the mixing work is also insufficient. Problems related to the mixing work and its management are revealed in practice as a measured non-homogeneity of the columns (so-called hour-glass phenomenon), which increases implementation costs and reduces the work quality, reliability and broader applicability. With reliable documentation of the mixing work and binder feed, the quality of the end product can be controlled, unlike with the current established quality control.

Objectives The main objective of the research was to study and develop a 3-D functional process for deep stabilization, and the sub-technologies and methods needed for these, in which the efficiency and quality of the measuring, planning, implementation and realization measuring process can be improved.
METHODS

Model for 3-D Automated Deep Stabilization

The target automation process of the research in the application area of deep (column) stabilization includes several different parts and phases (see Fig. 2):

1. Measurement of continuous 3-D representation of soil model and water content (clay, mud) using point-specific, sampling and continuous site investigation technologies.

2. 3-D planning of the stabilizing column field (stabilizing area, quantity of required columns, length and diameters of columns, distances between columns), targeted strengths and settlement properties.

3. Connecting opportunities for real-time measurement characteristics of the input data for mixing blade of machine.

4. Optimization of the feeding of stabilization binder for the column field using 3-D machine control model.

5. Automated 3-D control or guidance of the work machine.

6. Continuous measurement of the as-built data.

7. Real-time evaluation of the column-specific soil composition relative to target.

8. Automatic documentation of the implementation process, wireless data transfer for obtaining machine control and for sending realization data.

Experiments

The development possibilities of initial data surveying was tested using an electric tomography measurement system to observe electric resistivity of ground. The results were converted into 3-D water content model. The development of design process was tested using Citycad software as a base modeling tool, and by programming the need additional tools for enabling the initial data conversions. Furthermore, continuous 3-D soil model interpreted following the inversion of the input data measurements, including 3-D representation of water content, data of stratigraphic layers and soil types. A 3-D plan of deep stabilization columns including also the optimized binder amount calculation was designed and created. The 3-D machine control process of deep stabilization machine was studied by observing the use of two new different commercial 3-D control systems in real construction sites. The development possibilities of the feeding of stabilization material was studied by testing the measurement of the rotating moment of mixing blade as well as the force need to lift or press down force of the blade. In addition, a measurement test of stabilization material flow was done using a Solidflow sensor of SWR Engineering.

RESULTS

Observations about the development of initial data surveying

The opportunities providing geophysical measuring methods to generate site investigation data (3-D input data model) for the stabilization and piling needs were clarified. Electric, seismic and radiometric methods have been evaluated in the study, with the main emphasis on the electric methods. In stabilization, it is essential that the water content of the ground can be measured with electric and radiometric measurements. Electric measurements are a non-destructive method. With radiometric logging, the resistivity of the ground is converted into a continuous water content tomography (Fig. 3-4).

From the electric methods, the resistivity sounding and induced polarization (IP) methods have been tested by field tests. Between the electric resistivity and ground water content there is a model, with which the results of the resistivity measurements can be converted into water content. Induced polarization gives potential additional information on the soil
layers because the method also reacts to grain size changes.

Fig. 4. Continuous 3D soil model interpreted following the inversion of the input data measurements, including 3D representation of water content, data of stratigraphic layers and soil types.

Data obtained from electric measurements is not useful for soil interpretation as such; a so-called inversion model must be performed for the data. The apparent resistivities and IP values obtained from the measurements are calculated by inversion as real resistivities and IP values. In the inversion, the most suitable model is applied to the measured data using the multidimensional method of the smallest sum of the square. Also, the layer data obtained from conventional probing and possible seismic sounding can be included as part of the inversion process to obtain more distinguishable results. Interpretation and conversion into other quantities, such as water content, are performed on the data obtained from the inversion. It is also essential that the inversion be made so that the surface variations of the measuring range, i.e. topography, are taken into account.

Conventional reflection and refraction seismic surveys produce soil layer data with ±10 % measuring accuracy. Furthermore, the SASW method (Spectral Analysis of Surface Waves), radiometric logging, TDR method (Time Domain Reflectometry) and NMR method (Nuclear Magnetic Resonance) have been examined.

A new type of continuous 3-D ground mapping method based on the electric tomography measurement has been created in the research. A discordant description of stratigraphy created by sampling the probing and spot type is complemented with electric resistance and charge reversal measurement in the method and is changed into a continuous 3D representation of the water content. The water content has been established as the determining characteristic regulating the stabilized soil material strength and the required binder quantity. With the help of the water content and empirical water/binder ratio, the shear strength to be achieved with stabilized mass can be estimated. Furthermore, data on the organic content of the ground is required because part of the binder quantity must be used to neutralize the humus acid before the desired strength target can be achieved. Based on the strength targeted, the most suitable binder type is selected. Following the binder type selection, the mixing work quantity required (mixing head type and mixing efficiency), as well as the binder quantity to be fed to each place (x,y,z), are specified.

Observations about the development of design process

Design process was started by importing the initial data models into Citycad software. The design of soil improvements by deep stabilization was any time considered as a part of wider road or facility area design. A transformation of tomography measurements into a continuous 3-D representation of the water content was made. The 3-D topography of a test site was measured. Designer determined the needed stabilization columns and their demanded geotechnical resistance (Fig. 5-6). Furthermore, the optimal amount of binder material was calculated to every columns varying freely trough total column length. A new LandXML based transformation format extension was developed for the open information transfer in the research.

Fig. 5. A 2D scene of the Deep Stabilization Plan for a Road Construction Project in Finland (CityCAD, Sito Oy).
Observations about the use of 3-D control system in deep stabilization machine

During the last few years two different 3-D control systems for the control of deep stabilization machines were developed in Finland (Novatron Oy and Scanlaser Oy). Two GNSS antennas were used for the positioning of the machine (Fig. 7-8). The researchers of POHVAII project executed several work studies in different sites to observe the new features and efficiency of 3-D guidance in practical stabilization work. Four studies concerned the traditional work processes and two studies of 3-D controlled sites were executed. The direct work time consumptions of these two methods were not significant. However, several other benefits were observed: no wooden sticks were needed to be measured and installed before machine work and no waiting for measurements were any more needed. Furthermore, the use of 3-D machine control systems in deep stabilization machines was fast increased in Finland and Sweden during the last years. In Finland, about 50% of machines has been evaluated to been equipped with 3-D system today.

Results of soil resistance measurements
Based on the measured rotating moments and down press forces, it seems to be possible to identify and determine the features of soil layers and different material properties. The main results are shown and illustrated in the Figures 9 and 10.
Results of the tests of binder flow

The pressure sensors installed into the feeding pipe of stabilization material can be utilized in the identification of possible blockages inside the pipe. The tested Solidflow sensor did not work in the material flow measurement due to the insufficient measurement range of the sensor. The main results are shown in the Figure 11.

Fig.11. Test results of binder flow test using Solidflow sensor compared with the weighing results of the binder tank.

CONCLUSIONS

The automated process of deep stabilization was to be developed and tested having several different test methods including. Partly the tests indicated the full utilization possibilities of the process model and some parts, partly some of the tests indicated the functionality of the model and some parts could not to be verified. The automated process model was, however, decided to be introduced.

In the new automated visionary process model of deep stabilization, the traditional soil surveys are to be supplemented by electric tomography measurement in 3-D, with which the spatial water content of the object soil bed is to be determined. As a part of 3-D design process, the optimal amount of stabilization material to be fed into the object soil is to be calculated. Deep stabilization machine is to be controlled using a 3-D control system having the guidance working principle. Traditional marking measurements with wooden sticks are not yet needed. The control system measures continuously the amount of fed stabilization material and adjusts the feeding according to the machine control model. During the work process, the rotating resistance as well as the press down force are measured using the special sensors needed. At the same time, the system calculates and re-models more accurately the soil model, differs the different soil material layers and their shear resistances. All of the key information of the completed stabilization work is to be saved, documented and further shared with the owner, general contractor and stabilization contractor enabling also the full realization of the billing of the project. The further orders of stabilization material are also automatically sent based on the saved as-built information. This process model includes strongly the idea of real-time adjustment of the construction process.

References

Automating fabrication sequencing for industrial construction

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Purpose Industrial construction projects are heavily dependent on pre-fabrication of piping components. Unlike traditional manufacturing, many pipe spools have a unique design and need to be custom fabricated due to the one-of-a-kind characteristic of each industrial project. This is reflected in the fact that fabrication sequences vary greatly among pipe spools. Planning these sequences has considerable impact on the fabrication performance. However, it is currently mostly done in the form of human manual input. Personal experience and judgment are the major grounds on which sequencing decisions are based. Given the enormous number of pipe spools and the fast-tracking nature of industrial projects, the efficiency and quality of such decisions cannot be guaranteed. Automating this decision-making process has the potential for overall performance enhancement, but has not yet been sufficiently investigated.

Method We explore two different problem solving techniques, mainly artificial intelligence (AI) planning and dynamic programming (DP). A number of experiments have been conducted to evaluate their effectiveness.

Results & Discussion The results show that AI-planning—a sophisticate planning technique—has difficulty parsing fabrication logic that is prerequisite for AI-planners to result in a solution. DP, on the other hand, shows greater flexibility in incorporating this logic and a higher efficiency of discovering the optimal sequence. Future research will be aimed at incorporating the DP-algorithm with a discrete event simulation model so that fabrication sequences can be dynamically generated and adjusted to address changing project conditions.

Keywords: automated planning, industrial construction, artificial intelligence planning, dynamic programming

INTRODUCTION

Industrial construction projects refer to a wide range of facilities for oil/gas mining and production, power plant, food, and pharmaceutical purposes. Many industrial projects are mega projects (especially in the oil and gas industry), meaning that they are large scale, require intensive capital, and involve complex technologies. Piping is an indispensable component of industrial construction projects which is used to connect various processing units and equipment and to convey processed gas and fluid. Piping is always the largest single job (Kim and Ibbs 1995) and a critical and costly process in an industrial construction project (BRT 1982). To avoid trade stacking and congestion on the construction site, a piping system is broken down into pipe spools which are usually fabricated in off-site shops. Fabrication shops are controlled environments and they normally enjoy higher productivity than on-site activities.

Pipe spool fabrication is critical in the entire piping process, since it produces the pipe spools which are building blocks for downstream processes (e.g. module assembly and site installation). However, in reality, it is usually not pipe spool fabrication that drives the whole piping process. Due to the fact that many industrial construction projects are executed in a fast track manner, all piping stages could be more or less overlapped, which means pipe spool fabrication and installation could start even before the design is complete. It is often the availability of pipe spool drawings and site installation that drive the pipe spool fabrication. Pipe spool fabrication strives to fit its work to the sequence of the site installation given the availability of ISO drawings and raw materials. This leads to a lot of problems later in the shop operation. For example, pipe spool fabricators often contend with out-of-sequence or late supply of ISO drawings. They also suffer from the rush order or change order from the site installation. It is not uncommon for pipe spool fabrication shops to experience productivity loss, missed due dates, and incurred extra costs.

The sequence of pipe spool fabrication has a significant impact over the shop performance. Di and Mohamed (2011) conduct a simulation experiment to test if different fabrication sequences can lead to different shop performance. The results show that by varying the fabrication sequence for 22 pipe spools, the total cycle time can be reduced by 10.09%, and the number of handlings (i.e. considered as non-value-adding activity) can be decreased by 16.88%. The capability to identify the optimal fabrication sequence for pipe spools is therefore critical for fabricators to maintain their performance in a project environment full of uncertainties.

In reality, the fabrication sequences of pipe spools are often decided by shop foremen in a very heuristic
manner (i.e. primarily based on personal experience). Given the enormous number of pipe spools involved in an industrial project and the fast track nature of project execution, it is rather challenging for human planners to determine fabrication sequence with both efficiency and quality. There is a potential for performance improvement if this manual decision making process can be automated. This paper explores two candidate solutions to automatically identify optimal fabrication sequence for pipe spools. The first solution uses Artificial Intelligence (AI) planning technique, while the second adopts the dynamic programming (DP) technique. A number of experiments have been done in both solutions and the results show that AI planning is constrained by its numerical assignment and calculations capability and it could require special pre-processing of the input that could be computationally prohibitive for complex pipe spools. DP technique, on the other hand, offers a great flexibility of accommodating both numerical calculation and logical complexity (e.g. various fabrication rules). It displays quite satisfactory computation efficiency. In addition, DP also guarantees a global optimal solution. A conclusion is thus drawn that the DP technique is more suitable than AI planning to solve the pipe spool fabrication sequencing problem.

Pipe Spool Fabrication
Pipe spools are fabricated in fabrication shops from a group of raw materials, i.e. raw pipes and pipe fittings (elbows, flanges, nozzles, and etc.). The fabrication process consists of three major steps: (1) pipe cutting, (2) fitting (temporary connection), and (3) welding (permanent connection). Usually some of the pipe spool components are fitted and welded first before it is fitted with other components. The back-and-forth between fitting table and welding stations will continue until the all pipe spool components are fabricated.

Two types of fitting and welding are exercised in the fabrication shop—roll and position (in Figure 1). The selection is made by whether the arm length is longer or the clearance limit of rolling machines or not. If it is within the clearance limit, roll fitting and welding can be performed and the main pipe run can be rolled by a rolling machine, whereas if it exceeds the limit, position fitting and welding is the option and the fitter or the welder has to move around the main pipe run to accomplish fitting or welding. Since position fitting and welding involves much more manual effort, it usually takes a much longer time than roll fitting and welding. One major objective of pipe spool fabrication sequencing is to minimize the number of position fitting and welding processes.

The fabrication sequence defines the process of how a pipe spool will be fabricated gradually from raw materials (e.g. pipes and fittings), to intermediate sub-assemblies, and eventually to the final product. Usually, a pipe spool can be fabricated through a number of alternative sequences. However, in reality, sequence is determined by shop foremen in a very heuristic manner and these alternative sequences seldom have a chance to be compared and evaluated. As a result, opportunities of productivity improvement slip away.

Previous Research on Construction Sequencing
It should be noted that in this paper sequencing is more related to logic dependency between processes by considering the geometric and technological requirements, than the sequencing or prioritizing processes (i.e. those that compete for the same type of resource) given limited resource availability. A review of relevant research reveals two major topics: (1) identify underlying construction sequencing rationales, and (2) develop planning systems to automate the sequencing process. Inter-relationships between building components are often used as rationales to derive construction sequence. Researchers (Gray 1986, Kartam and Levitt 1990, Navinchandra et al. 1988, Jin et al. 1992) identified various inter-component relationships, such as “covered by,” “weather protected by,” “supported by,” “enclosed by,” “connected to,” as well as “damaged by.” Echeverry et al (1991) enriched the body of knowledge and categorized reasons for precedence relationship into four groups, namely “physical relationships among building components,” “trade interaction,” “path interference,” and “code regulations.” Under each category, they comprehensively enumerated more specific sequencing rationales. Other researchers have attempted to develop AI planning systems that capitalize on the existing construction sequencing rationales and automatically generate sequential dependencies between construction activ-
Planning has been one of the major AI research areas since 1960s (Newell and Simon 1972), Planning refers to selecting a sequence of actions that leads to a system (i.e. on which actions are applied) transforming from its initial state to a specific goal state. State is usually expressed in the form of a set of propositions. The state of a system is usually depicted by the states of all its constituent objects at a certain point of time. A number of actions are available to choose from and to apply on the system (or some of its constituent objects). Each action has its own precondition(s). An action is only applicable when the current state (of the system or of constituent objects) matches its entire precondition(s). Each action also has an explicit effect, which is the resulting state of the system (or the objects) after performing the action. Based on all this description, a planner carries out a state-space search or a plan-space search and identifies a sequence of actions to achieve the goal. If evaluation criteria are provided, some AI planning systems are able to identify optimal sequences of actions. This type of planning is sometimes also referred to as general-purpose planning.

Domain-independent AI planning

Planning Domain Description Language (PDDL) is one of the domain-independent AI planning languages (such as STRIPS or ADL). It was first developed by Drew McDermott (1998). Since then, it has evolved and refined through several versions. Domain-independent AI planning languages have been successfully implemented in many domains such as robot navigation, manufacturability of machined parts, and emergency evacuation.

Darwiche et al. (1989) argued that domain-independent AI planning is not a suitable approach to plan and sequence building construction projects. The major reason is that domain-independent AI planning fails to take advantage of domain knowledge (i.e. building construction) to reduce its search space and consequently has to carry out an extensive search. This leads to a few negative consequences such as computation inefficiency and sometimes inability to find an optimal plan. However, it should be noted that the context of this argument is fully limited to building construction. As mentioned before, pipe spool fabrication is a domain that fundamentally differs from building construction (i.e. building blocks, logic, inter-relationships). In fact, pipe spool fabrication has a number of distinguished features that make it a good candidate problem to be solved by domain-independent AI planning technique.

First, pipe spool fabrication does not have to deal with a wide range of objects and actions. A pipe spool usually comprises a number of pipes and fittings. However, they all can be viewed as one object class—pipe spool component—when it comes to welding. What matters is NOT the type of the component but rather the minimum and maximum coordinates (i.e. X, Y and Z) of the component. Only two actions are available to change the state of a pipe spool or pipe spool component—roll-welding or position-welding. This differs greatly from building construction where a wide variety of objects (e.g. footings, columns, beams, walls, doors, windows, etc.) are involved and hundreds of actions are required to build these components. It is also difficult to enumer-
ate all possible actions available to apply to the building components (Darwiche et al. 1989). Second, in the pipe spool fabrication world, every pipe spool component has only two different states—welded or not welded. The preconditions for welding action are quite simple—two pieces of sub-assemblies (or components) and one unfinished welding point (i.e. the welding point connects these two sub-assemblies). Its effect is a new sub-assembly (could also be the final pipe spool). However, it is difficult to abstract the state of building components as well as to define the preconditions and effects for building actions (Darwiche, 1989).

Application of PDDL to pipe spool fabrication sequencing problem

Using PDDL to solve a planning problem entails a modeling process which results in two pieces of description. The first one is called domain file and provides a general description of the system (i.e. pipe spool fabrication system). Basically it describes what types of objects are involved in the system, what states are possible for each type of object, what actions are available, and what the pre-conditions and post-conditions are to execute these actions. Another description is called problem file which provides a specific description of a particular problem for this system. For example, it includes a number of instances of objects, each with a specific initial state and a goal state. Figure 2 shows example domain and problem files that are customized for a pipe spool fabrication problem.

A number of experiments are conducted to test the capability of AI planners to solve the pipe spool fabrication sequencing problem. These experiments are designed to be of incremental complexity. Figure 3 shows the configurations of pipe spools used in these experiments. It should be noted that although the pipe spool in experiment 3 seems to have a simpler configuration than the one in experiment 2, experiment 3 involves the major challenge of consideration of dimensions of components. The ability to calculate and track changes in the dimensions of spool components (or sub-assemblies) throughout the fabrication process is essential to distinguish roll welding and position welding. The domain file for pipe spool fabrication system is formulated and problem files for all pipe spools are also specified. Meanwhile, three popular AI planners (domain-independent) are selected: (1) Metric-FF (Hoffmann 2002); (2) LPRPG (Coles et al. 2008); (3) LPG (Gerevini and Serina 2002). These planners are tested in all experiments and show a varied level of competence. The results of all experiments are discussed in detail by Di and Mohamed (2012). It is indicated that none of the AI planners are fully adequate to solve real-life pipe spool fabrication sequencing problems. Specifically, Metric-FF has no problem handling all kinds of pipe spool fabrication logic but does not well support numerical assignments and calculations (i.e. in experiment 3). An illogical fabrication sequence is returned in experiment 3. LPG, on the other hand, contends with conditional effects. In order to release the conditions from the effects of actions, a grounding process must be completed. This requires making actions more specific and enumerating all possible situations (i.e. the domain file needs to define more specific actions). The result from experiment 3 shows that after the grounding process, LPG is able to return a logical fabrication sequence for the pipe spool. However, there is a side effect of the grounding process: the number of actions defined in the domain file grows exponentially with the number of welds in the pipe spool. For example, a pipe spool has N welds and then $2^{N-1}$ actions need to be explicitly formulated in the domain file (e.g. a pipe spool with 13 welds requires 4096 actions defined). This poses a huge challenge (i.e. could be computation prohibitive) to solve some extremely complex pipe spool problems. This finding led to a search for other problem-solving techniques that have the potential to tackle the pipe spool fabrication sequencing problem. Dynamic programming has been found to be a good candidate.

Fig.2 Example domain and problem definition files for pipe spool fabrication (Di and Mohamed 2012)
Dynamic Programming

Dynamic programming (DP) is a generic, efficient approach to solve optimization problems that involves a succession of decision making processes. More specifically, these problems should possess two features. First, the problem can be broken down into sub-problems whose solutions will be reused a number of times. This is called overlapping sub-problems. Another feature is that the optimal solution of a problem can be constructed from the optimal solutions of its sub-problems. This is referred to as optimal substructure. Compared to brute force approaches, DP improves the computation efficiency and guarantees a global optimal solution. It should be noted that DP differs from many other optimization algorithms which contain a universal algorithm that applies to every problem. To use DP, every problem needs to be custom formulated and involves innovative thinking.

Analysis of Pipe Spool Fabrication Sequencing Problem from DP Perspective

DP solves a problem through recursively decomposing the problem into sub-problems until their solutions are trivial and then constructing the optimal solution in a bottom-up manner by continuously selecting the optimal solutions for sub-problems which later become the basis for the optimal solution of the immediate parent sub-problems. This solution construction process stops when the sub-problem becomes the original problem itself. Following this same idea, the pipe spool fabrication sequencing problem is analyzed. Before going into detailed analysis, it is assumed that a roll-welding costs 1 while a position-welding costs 2. The optimization problem is now converted to find the minimum cost sequence to fabricate the pipe spool.

First, the optimal sequence to fabricate a pipe spool depends on the optimal sequence to fabricate its sub-assemblies. Figure 4 shows that the pipe spool could be decomposed at each welding point (i.e. stage 1 level). Each decomposition option results in a pair of sub-assemblies (could be pipe spool components as well). The cost to fabricate the pipe spool can be expressed in following equation:

\[
\text{Cost}_{\text{pipe spool}} = \text{Cost}_{\text{sub-assembly1}} + \text{Cost}_{\text{sub-assembly2}} + \text{Cost}_{\text{to weld sub-assembly1 and sub-assembly2}}
\]

To determine which option is superior to fabricate the pipe spool, it is necessary to know the minimum cost to fabricate all these sub-assemblies, which in turn depends on the minimum cost to fabricate their children sub-assemblies. The decomposition stage 2 in Figure 5 shows how sub-assembly 6 and 7 are further decomposed. It is noted that all of their children sub-assemblies are already atomic components (i.e. pipes or fittings). Therefore, it cost nothing to weld them. The minimum cost for sub-assembly 6 is determined as following.

\[
\text{Cost}_{\text{sub-assembly6}} = \text{Cost}_{\text{to weld component1 and component2}}
\]

It is found that the minimum cost to fabricate the sub-assembly 6 is equal to the cost to weld component 1 and 2, which makes it simple to determine whether it is a roll-welding or a position-welding. Given that the rolling axis is around the component 2, the arm length is \(H_2\) (0.5m) and less than the rolling clearance (1.5m). It is then a roll welding. The minimum cost to fabricate sub-assembly 6 is 1.

\[
\text{Cost}_{\text{sub-assembly6}} = \text{Cost}_{\text{to weld component1 and component2}} = 1
\]

The minimum cost for all the other sub-assemblies can be determined in a similar way. The process is always to decompose the pipe spool (or sub-assembly) to atomic component level where the fabrication cost is easy to determine. From this point, the solution can be constructed in a bottom-up manner. For example, connecting component 1 and 2 is the minimum cost and the only way to fabricate the sub-assembly 6. The same is for the sub-assembly 7. Then if connecting sub-assembly 6 and 7 is also the minimum cost sequence to fabricate the whole pipe spool (i.e. in fact it is), then the optimum sequence is formed.

Stage 1: \(\text{Component1} + \text{Component2} \rightarrow \text{Sub-assembly6}\);

Stage 2: \(\text{Sub-assembly6} + \text{Sub-assembly7} \rightarrow \text{The Pipe spool}\);
Application of DP Algorithm to Pipe Spool Fabrication Sequencing Problem

Based on the foregoing idea, a DP algorithm is designed to solve the pipe spool sequencing problem. So far, it has been tested with a number of pipe spools. One of pipe spools is considerably complex and its configuration is shown in the Figure 6. The algorithm solves the problem within one and half minutes and returns a fabrication sequence shown in Table 1. It should be noted that because there is more than one optimal sequence in this case, a different sequence could be returned if the algorithm runs several times, but they all incur the same minimum fabrication cost.

Table 1. Fabrication sequence returned from DP algorithm

<table>
<thead>
<tr>
<th>Stage No.</th>
<th>Welding Point</th>
<th>Resulting Sub-assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>[2, 6]</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>[2, 6, 4]</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>[3, 9]</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>[2, 6, 4, 8]</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>[1, 7]</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>[2, 6, 4, 8, 3, 9]</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>[1, 7, 11]</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>[5, 10]</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>[1, 7, 11, 2, 6, 4, 8, 3, 9]</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>[5, 10, 12]</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>[5, 10, 12, 1, 7, 11, 2, 6, 4, 8, 3, 9]</td>
</tr>
</tbody>
</table>

Fig. 4 Decomposition of an example pipe spool (Stage1)

CONCLUSION

Fabrication sequence is of significant impact on pipe spool fabrication performance. Current industry practice relies heavily on shop foremen’s personal experience. Previous research on construction sequencing is mostly focused on building construction and therefore not readily applicable to pipe spool problems.
Fig. 6 an example pipe spool solved by Dynamic Programming

Gaps exist in the current body of knowledge related to automated process sequencing on industrial construction. This paper explores two potential problem solving techniques: domain-independent AI planning and Dynamic Programming. Observations from a number of experiments indicate that a DP-based algorithm outperforms AI planners in the capability of handling numerical assignment calculations and it also displays quite satisfactory solutions and computation efficiency. This leads to a conclusion that DP is more suitable for solving the pipe spool sequencing problem than AI planning. Future work will be directed to experiment more pipe spools and use simulation to quantify the performance improvement gained by using the DP algorithm. Another direction is to incorporate the DP algorithm with a simulation model so that fabrication sequences can be dynamically generated.

References

Shape recognition with point clouds in rebars

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Purpose In this paper, the authors describe the methods of inspecting the quality of reinforced concrete structure using point-clouds data acquired from a 3D-laser scanner. A 3D-laser scanner is an outstanding device to analyze a real-world object and to collect digital data on its shape. Inspections of the quality of reinforced concrete structure using point clouds are required for novel methods which count the quantity of rebar material and to check the space of each rebar.

Method To inspect with the use of 3D point clouds, we developed a method of 3D-point-clouds recognition of the rebars elements. In this paper the authors show three methods to analyze point clouds collected in rebars of building structures. Firstly, the authors developed a method of noise reduction to make a clear distinction between object surface points and noise points; this is important because point clouds in rebars have much noise that can disturb subsequent analysis. Secondly, the authors developed a method of abstracting point clouds on reinforcement bars. Thirdly, the authors developed a method dividing point clouds on reinforcement bars into hoops and wall horizontal reinforcement bars. The authors scanned reinforced bars of columns and walls at a construction site of an apartment and then applied the three methods to analyze the point clouds data. Results & discussion In this experiment, our methods were able to identify 3D point clouds as main bars, horizontal bars, and hoops. We were able to measure the object from 3D-point-clouds data at any time as well as being able to develop an automatic inspection system.

Keywords: quality control, 3D laser scanner, 3DCAD, point cloud, reinforcement work

INTRODUCTION

A 3D scanner is an outstanding device to collect digital data as 3D point clouds and analyze a real-world object. These digital data facilitate the measurement at any time because point clouds record the shape of an object. There have been many studies1 of 3D scanner in mechanical engineering and civil engineering. In recent years, there have also been similar studies2 in building engineering. In construction engineering, many researchers have adapted 3D scanner to create 3D building models and have developed the method3 of the shape recognition of 3D point clouds. However, many studies in construction engineering have dealt with point clouds data processing in order to identify semantic feature, such as walls, floors, ceiling, windows or rooms. The authors have developed a system to inspect the quality of reinforced concrete structure using point clouds data acquired with 3D laser scanner, focusing the shape recognition of 3D point clouds in reinforcing bars. The building regulation in Japan has defined the rebar arrangement for resistance to collapse. The structure engineer determines the diameters of bars, an arrangement of vertical bars, and the size and spacing of columns ties. Therefore, the construction workers have to confirm the rebar arrangement. But, rebar inspection is hard work and time-consuming work because many confirming spots exist in a construction site. Thus, the authors have developed the methods of inspecting rebar arrangement. In this paper, the authors show the three methodologies to analyze point clouds of reinforcing bars in construction sites: noise reduction, abstraction of point clouds of reinforcing bars, and shape recognition of vertical bars, columns ties, and horizontal bars of walls.

THE METHODS OF ANALYZING POINT CLOUDS

Point clouds of steel reinforcing bars

Steel reinforcing bars (“rebar”) for concrete construction is commonly used as a tensioning device in reinforced concrete. Rebar arrangement differs from columns, beams or walls. Columns contain two types of reinforcing bars: Vertical bars with a larger-diameter share the compressive loads with the concrete and resist the tensile stresses. Ties with a smaller-diameter are wrapped around the vertical bars. The ties may be either of two types: column...
ties or column spirals. In Japan, column ties are typical ties. Vertical bars and column ties are often a rectangular arrangement.

The authors scanned the reinforcing bars of the column and the wall using 3D laser scanner (Figure 2) and obtained the point clouds of reinforcing bars (Figure 3). Point clouds of reinforcing bars record arrangement of reinforcing bars, but they often include many noises (Figure 4). Point clouds of vertical bars are similarly to cylinder because vertical bars have large-diameter bars (Figure 5). On the other hand, point clouds of column ties and bars in walls are linear, because column ties and bars in walls use bars with a small-diameter (Figure 5 and Figure 6).

Steps of automatic inspection system

Acquired raw point clouds data have a lot of noises, and do not provide the accurate semantic information of the structure. Therefore, the authors developed the method that extracts semantic information about rebar inspection from raw point clouds. The automatic rebar inspection system consists of the following five steps:

(a) Noise reduction makes a clear distinction between object surface points and noise points
(b) Multiple scans from different directions are brought in a common coordinate system, which is usually called “registration”, and then merged into the complete point clouds data
(c) Point clouds of reinforcing bars are abstracted from the merged point clouds
(d) Point clouds are decomposed into three pieces: the linear point clouds which are vertical and parallel to the wall baseline, as well as point clouds of which direction is parallel to the floor and is at right angles with the wall baseline
(e) Pieces are assembled into characteristic configuration at a higher semantic level, e.g., vertical bars of columns, columns ties, vertical bars of walls and horizontal bars of walls

Noise reduction

When 3D laser scanner is applied to reinforcing bars, the point clouds contains many noises. A point becomes a noise when the laser spot is distributed on several surface parts with different distances from the scanner (A point “P_i” in Fig. 7 represents a noise). Therefore, there are two characteristics: a point of noise has a longer mutual distance between the two points, and the density of point clouds is thin.

Noise reduction which is based on mutual distance sorts out a noise by an interval between two points. Using 3D scanner, the authors control the scanning interval on objects (bars) smaller than 4mm. Therefore, if an interval between the points is larger than the scanning interval, the point should be a noise.

\[ d_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2 + (z_i - z_{i-1})^2} \]

\[ d_i > \alpha D \quad \text{and} \quad d_{i+1} > \alpha D \quad \text{...}[1] \]

D : D is a set point interval of 3D scanner
\( \alpha \) : Noise recognition coefficient (about 1.5~2.0)

Fig.7. Noise characteristic
When a point of \([i]\) is \(P(i)\), “\(d_i\)” represents the distance between \(P_i\) and \(P(i+1)\). The scanning interval is \(D\). The distance “\(d_i\)” is obtained from the following equation. If formula \([1]\) is satisfied, \(P_i\) should be a noise.

Additional noise reduction is based on the density of point clouds. A point on the surface of an object is usually in a large number of point clouds per unit volume of a cube. By contrast, a noise point is in a small number of point clouds. Thus, it is possible that noise is detected by the density of point clouds.

Fig.8 Noise reduction based on density

Abstracting point clouds of reinforcing bars from raw point clouds

The method of abstracting point clouds of reinforcing bars
Point clouds of reinforcing bars have a complicated shape. Therefore the point clouds of reinforcing bars cannot be distinguished directly from raw point clouds by using the mathematical methods such as least-square method. Hence, the authors have developed a method of abstracting point clouds of reinforcing bars from raw point clouds.

The method of abstracting point clouds of reinforcing bars in three dimensional spaces
Point clouds of reinforcing bars are not a primitive shape such as plane, sphere and cylinder. Although point clouds of a primitive shape don’t include point clouds of reinforcing bars, point clouds of non-primitive shape include more much point clouds of reinforcing bars than raw point clouds data. Therefore, if point clouds of a primitive shape are removed from raw data, point clouds including reinforcing bars remain.

Fig.9 Point clouds put into voxels and then replacing planes using least-square method

Fig.10 Point clouds of sphere replacing a sphere model using least-square method

Raw point clouds are put into voxels which represent a value on a regular grid in a three dimensional space (Figure.9). Next, the point clouds in a voxel are fitted into a sphere and plane by the least-squares method. If the sum of the squares of the errors is less than tolerance, the point clouds are fitted into a sphere (or a plane) model and then the point clouds are removed from raw data (Figure 9 and 10).

Fig.11 An example of the flow diagram dealt with shape recognition in three-dimensional spaces.

Remaining point clouds, which include point clouds of reinforcing bars, go on to next steps for abstracting point clouds on reinforcing bars in a cross section.

Steps of abstracting point clouds on reinforcing bar in a cross section
The method of abstracting point clouds on reinforcing bars in a cross section are developed by the authors consisted of the following three steps:

(a) The point clouds are sliced in horizontal 2D cross sections (Figure.12)
(b) In a cross section, point clouds is grouped by taking account of the continuity between pixel blocks (Figure.13 and 14)
(c) The system recognizes the shape in each cluster of point clouds and then distinguishes point clouds on reinforcing bars (Figure.15)
Replacing point clouds with pixel blocks and making a group of neighboring point clouds. The sliced point clouds are analyzed with pixel blocks. The pixel block is a 5mm square. If a point is located in a pixel block, a point replaces a pixel block as shown in Figure.13.

After replacing all point clouds, pixel blocks are grouped by taking account of the continuity between pixel blocks. Neighboring pixel blocks are four neighboring squares (Figure.14).

Shape recognition of grouped point clouds in a cross section
The system then recognizes the shape in each cluster of point clouds. The classification of shapes in a cross section is shown in Figure.15.

When point clouds on vertical bars are sliced in a horizontal cross section, the density of point clouds on the cross section is high. On the other hand, when point clouds on horizontal bars are sliced in a horizontal cross section, point clouds in the cross section appear in a line. Thin point clouds are noise or unrecognizable points. Point clouds on the floor appear as a plane. Therefore, dense point clouds and circular point clouds should be point clouds on a rebar.

Method of making a distinction between vertical bars and the others
Because the shape recognition in a cross section makes some mistakes, the authors also developed a method making a distinction between vertical bars and the others.

The shape of bars is normally a smooth curve. Therefore, if point clouds are on a vertical rebar, clusters of dense point clouds could tie them in a row (Figure.17).

By contrast, if clusters are not on a vertical rebar, clusters of point clouds cannot tie them in a row.
Decomposing point clouds into the linear pieces

The reinforcing bars of walls and columns are arranged in a specific direction. The direction of wall reinforcing bars is either horizontal or vertical. A column tie is a rectangle and the rectangle is divided into two directions at the corners. Therefore, if point clouds of column ties are divided at the corners, they are decomposed into linear point clouds.

The system is able to slice point clouds not only in a horizontal plane but also in a plane which is at right angles to the wall baseline (Figure.18) as well as in a plane which is at right angles to both of the two planes.

On each plane, the system distinguishes point clouds on the vertical bars which are at right angles to the plane from the other point clouds (Figure.19). Finally, all point clouds of reinforcing bars are decomposed into linear point clouds.

Assembling pieces of point clouds into columns ties

After point clouds are decomposed into pieces, pieces of point clouds are assembled into column ties (Figure.21).

If pieces are column ties, the distance between two lines is less than the diameter of each rebar

If pieces are not column ties, the distance between two lines is more than the diameter of each rebar

APPLICATION OF THE SYSTEM TO POINT CLOUDS OF REINFORCING BARS

Point clouds of reinforcing bars obtained by laser scanning

The authors scanned reinforced bars of columns and walls at a construction site of an apartment house (Figure .22).

To evaluate the system capability of inspection, the authors have applied the system to the point clouds of reinforcing bars.

Noise reduction

Fig.23 shows a result of noise reduction.

A. Acquired data  B. Mutual distance  C. Density

Fig.23 Noise Reduction

Fig.23.A depicts the acquired point cloud data. Fig.23.B shows a result of noise reduction based on the mutual distance. Fig.23.C shows a result of noise reduction based on the density. Almost all noises have been removed.

The result of abstracting point clouds of reinforcing bars in three dimensional spaces

Fig.24 shows a result of abstracting point clouds of reinforcing bars in three dimensional spaces.

Red point clouds are on a plane. Black point clouds are thin point clouds. Blue point clouds are remaining point clouds which include point clouds of rein-
forcing bars.

Fig.24 The result of abstracting point clouds of reinforcing bars in three dimensional spaces

**Distinction between vertical bars and the others**
After making a group of neighboring point clouds, the system recognized shapes in each cluster of point clouds and then abstracted point clouds on bars. Figure.26 shows a result of shape recognition.

Fig.25 Example of shape recognition in a cross section (Blue: Circular, Green: Massive, Yellow: Another)

These point clouds are not on a vertical rebar, but recognized on a vertical rebar

Fig.26 A result of Shape Recognition

Despite the fact that point clouds are not on a vertical rebar, a few point clouds are recognized on a vertical rebar because of the failure of shape recognition. However, Figure.27 shows a successful abstraction of point clouds by tying them in a row.

Fig.27 The result of abstracting point clouds in a smooth curve

**Decomposing point clouds into pieces**
Fig.28 shows a result of dividing point clouds of reinforcing bars at the corners and decomposing point clouds of reinforcing bars into linear point clouds. The directions of the linear point clouds are vertical and parallel to the wall baseline, as well as parallel to the floor and at right angles with the wall baseline.

Fig.28 Decomposing point clouds into three pieces

**Assembling point clouds into column ties**
The system assembled point clouds into column ties. Figure.29 and Figure.32 show the results of assembling column ties. Furthermore, Figure.31 shows the result of shape recognition of the point clouds.

Fig.29 The result of shape recognition of the point clouds

**CONCLUSIONS**
The authors scanned reinforcing bars of the columns and the walls at a construction site, then analyzed the point clouds data using the system described in this paper. In these experiments, the system was able to identify point clouds of reinforcing bars, and then successfully assemble them into column ties. The authors have been able to identify the shape of reinforcing bars, and then have been able to count the number of the column ties and the vertical bars.
1) The authors developed this system with VBA in MicroStation.

References
Automated pipeline extraction for modeling from laserscanned data

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Purpose

Three-dimensional (3D) as-built plant models are required for various purposes, such as plant operation, maintenance, and the expansion of existing facilities. The as-built plant model reconstruction process consists of as-built plant measurement and 3D plant model reconstruction. As-built plant measurement uses 3D laser scanning technology to efficiently acquire data. However, the current method used for 3D as-built plant model reconstruction from laser-scanned data is still labor-intensive. The objective of this study is to develop a fully-automated parametric reconstruction of the as-built pipe-line occupying a large portion of the area in an as-built plant.

Method

The proposed approach consists of three main steps. The first step is to extract the cylindrically-formed pipelines from laser-scanned data based on random sampling consensus (RANSAC). The second step is to segment the extracted pipelines into pipe components, such as straight pipe, elbow, and branch tee, based on medial axis extraction and curve skeletonization. The last step is to surface-model reconstruct the segmented pipe-lines using the parametric modeling method.

Results & Discussion

The experiment was performed at an operating plant to validate the proposed method. The experimental results revealed that the proposed method could contribute to automation for 3D as-built plant model reconstruction.

Keywords: automation, as-built modeling, as-built pipe, parametric modeling, RANSAC

INTRODUCTION

The pipelines of a plant play an important role in the operation, maintenance, and expansion phases of existing chemical, refinery, and power plants. Much equipment and instruments are connected only by the pipelines to perform their functions, so they play a role as an intermediary. Therefore, 3D as-built pipeline models can be used for maintenance and operation phases and expansion or modification of existing plants. For example, by using 3D as-built pipeline models for planning, expansion, and modification of existing plants, collisions between equipment can be detected. During the maintenance and operation phase, 3D as-built pipeline models can be used for efficient inspection and part replacement.

In practice, to generate 3D as-built pipeline models, laser scanners are used to measure plants, and then users manually generate 3D as-built models from laser-scanned data using commercial software packages. To generate 3D as-built pipeline models using commercial software packages, the user must extract laser-scanned data corresponding to each pipeline to be modeled in large laser-scanned data sets. After extraction of laser-scanned data corresponding to each pipeline, the user generates as-built pipeline models by using some functions in commercial software. However, manually identifying each pipeline is nearly impossible and is a very time-consuming and labor-intensive process because the laser-scanned data of the plant is huge and includes other objects such as structural components, containers, and equipment; the pipelines are also intricately entwined like a net. Thus, to efficiently generate 3D as-built pipeline models, automated pipeline extraction must be performed.

Research has been done to effectively extract pipelines from laser-scanned data by extracting cylinder. Rabbani and Heuvel proposed a method for extraction of cylinders in laser-scanned data using the Hough transform. Bey et al. proposed a method for extraction of cylindrical objects in laser-scanned data using Bayesian formulation to generate a 3D as-built model. Previous research shows that cylindrical objects can be extracted from laser-scanned data to generate a 3D as-built model based on extracted cylindrical objects. However, cylindrical objects include straight pipes as well as other objects like equipment. Therefore, extraction of entire pipelines including straight pipes, elbows, and junctions from laser-scanned data is still a laborious and challenging problem.

The aim of this study is to propose a fully automated process that allows extraction of a 3D as-built pipeline for modeling from laser-scanned data. The rest of the paper is organized as follows. An overview and details of the proposed extraction process of as-built pipeline are provided in Section 2. In Section 3, experimental result is provided. Finally, conclusion and recommendation for future research are given in Section 4.
A PROPOSED PIPELINE EXTRACTION METHOD

In this section, the proposed pipeline extraction process from laser-scanned data is presented. The pipeline extraction for modeling method consists of three main steps. The first step is to segment the laser-scanned data of an industrial plant into subsets based on a smoothness constraint. The purpose of segmentation is to subdivide the laser-scanned data of an industrial plant into meaningful subsets in order to extract an as-built pipeline in this paper. The laser-scanned data does not include topology information of objects and only contains the points with color information. However, an industrial plant is composed of primitive-shaped objects, meaning that each primitive in the laser-scanned data represents an object. Therefore, segmentation is first performed based on the smoothness constraint that can segment the laser-scanned data into primitives. In this step, segments of the laser-scanned data are computed. The second step involves classifying pipelines from subsets of the laser-scanned data based on approximating medial axis extraction, skeletonization, and radius calculation. The purpose of pipeline classification is to classify the segments of laser-scanned data into either pipeline or non-pipeline in order to generate the pipeline model automatically. The approximating medial axis extraction and skeletonization extract features from each segment. The result of the extracted feature can be used as the principal axis of an object. Pipelines of an industrial plant that require the principal axis as a parameter are cylindrical in shape. Therefore, pipelines can be classified by means of their characteristics based on approximating medial axis extraction, skeletonization, and radius calculation. The result of this step is the classification of an as-built pipeline from laser-scanned data. Finally, a 3D as-built pipeline model is generated using the skeleton of pipeline segments and their radii.

Laser-scanned data segmentation

Segmenting the laser-scanned data is performed using the smoothness constraint proposed by Rabbani et al. The smoothness constraint segments the laser-scanned data at the points that have high normal variances with neighboring points. The industrial plant is composed of primitive-shaped objects. Therefore, the laser-scanned data of an industrial plant can be subdivided into objects based on the smoothness constraint. The segmentation method consists of normal estimation and region growing. The normal estimation is performed first, as the segmentation points are calculated using normals of points. After normal estimation, region growing is performed. Region growing makes groups of points that have a smooth surface with neighboring points using the estimated normals and their residuals.

Normal estimation

The segmentation method embarks on normal estimation for each point. To estimate normal for each point, plane fitting to some neighboring points is performed. Neighboring points are computed for each point using k nearest neighbors (KNN), which selects the k number of points having minimum distance (Fig. 1(a)). In this paper, the nearest neighbor number k is set to 30 for the original study. The plane fitting finds the best fit plane that minimizes the sum of orthogonal distances from neighboring points. The normal of the plane is taken as the estimated normal for a point, and the residuals of plane fitting are taken as indicator of areas of high curvature (Fig. 1(b)).

Region growing

The region growing takes as input the estimated point normals and their residuals. The region growing is performed with two constraints. The first constraint is local connectivity. The constraint means that the points of a segment have to be locally connected. That would be enforced by using the k nearest neighbors. The second constraint is surface smoothness. The constraint means that the normals' variance has to be smooth. That would be enforced...
by using a threshold angle ($\theta_{th}$) between a seed point and the added points to the region of the seed point.

The process of region growing is as follows.

1. Specify a residual threshold $r_{th}$.
2. Define a smoothness threshold in terms of the angle between the normals of the current seed and its neighbors. If the smoothness angle threshold is expressed in radians, it can be enforced through dot product as follows $\|\mathbf{n}_p \cdot \mathbf{n}_q\| > \cos(\theta_{th})$.
3. If all the points have been already segmented, go to step 7. Otherwise, select the point with the minimum residual as the current seed.
4. Select the neighboring points of the current seed. Use KNN with the specified parameters for this purpose. The points that satisfy condition 2 are added to the current region. The points whose residuals are less than $r_{th}$ are added to the list of potential seed points.
5. If the potential seed point list is not empty, set the current seed to the next available seed, and go to step 4.
6. Add the current region to the segmentation and go to step 3.
7. Return the segmentation result.

**Pipeline extraction**

In order to classify a pipeline, the feature extraction is first performed using the approximating medial axis method proposed by Dey and Zhao\(^4\) and the skeletonization method proposed by Cao et al.\(^2\). Skeletonization is a suitable feature by which to classify pipelines, as a pipeline is cylindrical in shape, and the approximating medial axis is used to generate an accurate skeleton. Thereafter, a simple classification is performed based on the radius estimation of the points of each segment, using skeleton points as a principal axis.

**Pipeline feature extraction**

In the pipeline feature extraction, the approximating medial axis is performed using Voronoi diagram. The Voronoi diagram of the laser-scanned data is filtered with the angle condition and ratio condition to extract an approximating medial axis using its dual Delaunay edges from the Delaunay triangulation of the sample points.

Angle condition $\theta$ can be described as follows:

$$\max_{p,n_{pu}} \angle n_{pu}t_{pq} \leq \frac{\pi}{2} - \theta$$

Where $p$ and $q$ are sample points of input data; $U_p$ is an umbrella that is extracted from Delaunay triangulation; $t_{pq}$ is a tangent vector from $p$ to $q$; and $n_{pu}$ is a normal to a triangle $ptu$. Ratio condition $\rho$ can be described as follows:

$$\min_{n\in \text{KNN}_p} \frac{\|p-q\|}{R_{pu}} > \rho$$

Where $R_{pu}$ is the circumradius of a triangle.

After filtering, the Delaunay edges remaining are only those that satisfy both conditions. The remaining set of Voronoi facets from the Voronoi diagram creates the approximating medial axis\(^4\).

After performing the approximating medial axis, skeletonization is performed. The skeletonization algorithm takes as input the vertices of the result of the previous step. The algorithm embarks on the geometric contraction of the vertices based on implicit Laplacian smoothing, which removes details of the input data along the normal directions. The algorithm automatically chooses some anchor points to maintain the original shape of input data during the contraction. After the contraction process, the skeletal shape of the input data remains the result.

The geometric contraction first constructs a one-ring structure for all vertices. It is needed to use the Laplacian matrix to compute the normal direction of the vertices. To define one-ring neighbors, therefore, an approximate neighborhood of the vertex as a point $p_i$ is extracted by finding $k$ nearest neighbors and projecting the neighbors on its tangent plane. The contraction process can be described as follows. Assume that the following equation is solved for $P^{t+1}$:

$$\begin{bmatrix}
W_t L_t' \\
W_{H_t}'
\end{bmatrix} P_t^{t+1} = \begin{bmatrix}
0 \\
W_{H_t}' P_t
\end{bmatrix}$$

Where superscript $t$ is used to denote the $t$-th iteration; $L$ is a $n \times n$ Laplacian matrix with cotangent weights; $P$ is the input data; and $W_t$ and $W_{H_t}$ are the diagonal weight matrices balancing the contraction and attraction forces. Then, the diagonal weight matrices $W_{L_t}^{t+1} = S_t W_t^t$ and $W_{H_t}^{t+1} = W_{H_t}^t S_t^0 / S_t^1$ are updated, where $S_t^1$ and $S_t^0$ are the current and original neighborhood extents of point $p_i$, respectively. Finally, the new Laplacian matrix $L_t^{t+1}$ is constructed with the new point cloud $P_t^{t+1}$. The contraction process stops when the solution converges. The input data becomes a skeletal shape $C$. The result
of geometric contraction is not a 1D curve skeleton. Further steps are required to extract the 1D curve skeleton. The 1D curve skeleton is extracted by imposing an initial connectivity and computing edge contraction.

Pipeline classification
The pipeline classification method takes as inputs the segments and 1D curve skeletons of each segment. To classify pipelines, the distance from the 1D curve skeleton points to the surface points is computed for each segment. The surface points of a skeleton point are selected using k nearest neighbors. The nearest neighbor number k is set to 30. The radius of a segment is defined as the average distance from skeleton points to the segment surface, and standard deviations of the distances are computed for each segment. The classification is performed with the radii of segments and the standard deviations. The pipelines are roughly extracted using the radii of segments with a threshold \( \delta_r \) that defines the boundary between the minimum diameter of a pipe and the maximum diameter of a pipe. Finally, the pipeline is extracted to remove the segments that have a high standard deviation.

Skeleton based pipeline model generation
Once the skeleton points of extracted pipeline segments and their corresponding radii are obtained, the pipeline model is simply generated automatically by the parameters. The pipeline model is also classified by type of pipe components such as elbows, T-junctions, and straight pipes using the degree variation of skeleton points.

EXPERIMENTAL RESULT
In this study, the performance of the proposed pipeline extraction for modeling from laser-scanned data was tested on actual laser-scanned data. The result of the test is shown in Fig. 2. Fig. 2(a) shows a laser-scanned data acquired from an operating industrial plant and Fig. 2(b) shows the result of segmentation based on smoothness constraint. The segmentation result shows that most segments, which are displayed using various colors, represent each object. Fig. 2(c) shows extracted pipeline and Fig. 2(d) shows the pipeline model. In Fig. 2(d), the gray-colored models denote the models of straight pipes, the green-colored models denote the models of elbows, and the red-colored models denote T-junction. The threshold angle \( \theta_{th} \) was set to 15° for the original study and \( r_{th} \) was calculated by the 98th percentile of the residuals for segmentation. The threshold \( \delta_r \) was set to 2–10 inches for the diameters that were used for this industrial plant in the scene.
Fig. 2. Result of pipeline extraction and model generation; (a) Laser-scanned data; (b) Segmented laser-scanned data; (c) Extracted pipeline; (d) Generated pipeline model

The proposed pipeline extraction method was validated for precision rate, and the result is presented in Table 1. The precision rate shows that the percentage of extracted pipelines is calculated as the number of true pipelines over detected pipelines. It is observed that the precision rate of pipeline was 93.33%. Based on the experimental result, it can be concluded that the proposed method can be used to accurately extract the as-built pipeline for modeling by means of the automated process. The result shows a high precision rate, but the error occurred in incomplete data part due to occlusion or other visibility issues during acquiring laser-scanned data. The incomplete data leads to an under- or over-segmentation problem and that is the cause of the error.

Table 1. Performance of the proposed extraction method

<table>
<thead>
<tr>
<th>Detected Objects</th>
<th>True Objects</th>
<th>Precision rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipelines</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>

CONCLUSION

This paper proposes a new method that can automatically extract an as-built pipeline for modeling from laser-scanned data. The segmentation of the pipelines is performed by the smoothness constraint. The segments of laser-scanned data are then classified into either pipeline or non-pipeline using medial axis extraction, skeletonization, and radius calculation. The pipeline model is simply generated based on the skeleton points of extracted pipeline segments and their corresponding radii. The feasibility of the proposed method was demonstrated in an experiment using real laser-scanned data obtained from an operating industrial plant. The result shows that the proposed method can successfully extract the 3D as-built pipelines for modeling. The proposed method is advantageous as it extracts pipeline and generates a model automatically. Thus, it could be successfully incorporated into the development of as-built plant information modeling. Nevertheless, the proposed pipeline extraction method for modeling has a limitation that may extract objects instead of pipelines because of incomplete data. In order to extract the entire pipeline without errors, complete data is required, which does not contain holes. Therefore, future research should focus on the reconstruction of the incomplete laser-scanned data acquired from an industrial plant.

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REFERENCES


RFID Indoor Location Identification for Construction Projects

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Purpose The purpose of this paper is to present an indoor location identification methodology using low cost passive Radio Frequency Identification (RFID) for construction projects. Method Location-aware information at construction sites is an emerging area, concerned with automating the delivery of spatial information on the location of materials, workforce, and equipment. This spatial information can provide knowledge on construction project status. Most RFID localization literature focuses on deploying active RFID tags, which are expensive and aimed at indoor localization. It has been experimented with in operating buildings but not on construction jobsites and with a different time span. For this paper low cost passive RFID-tags were used. Using this methodology, a number of passive RFID tags are distributed onsite where work is progressing and the user, such as the field superintendent, carries a mobile RFID-reader. The indoor construction work-active area is divided into exclusive zones for tracking. Each passive RFID-tag is used as a reference point with known location (LANDMARK) within a predefined zone. The reference tag’s known location is used to estimate the location of the user. The methodology uses Received Signal Strength Indicator (RSSI) as the main attribute for signal measurement to process the reader captured data. Two localization algorithms (Trilateration and Proximity) were used to identify the user location. After identifying the user’s location, the user can take snapshots with a camera and write comments about onsite activities. The collected data will be then attached to the as-planned project schedule and related CAD drawings automatically at the identified location. This data is used to represent actual progress, which is then compared to as-planned baseline progress using earned value analysis. Results & Discussion An actual construction jobsite was used to build 5 test beds at different locations and different construction time spans. Experiments were conducted on the test beds to compare the results obtained from Trilateration and Proximity algorithms. The results show mean error equals to 1m for Trilateration method with standard deviation of 0.4m and for Proximity method mean error equals to 1.76m with standard deviation of 0.5m. Indoor location identification could be utilized for tracking the project status.

Keywords: RFID, indoor location identification, RSSI, trilateration, proximity

INTRODUCTION

Location awareness provides support for decision-making, timely tracking of the project status, proactive safety monitoring, and, subsequently, operation and maintenance of constructed facilities. Recent advances in sensing technologies have enabled the deployment of a range of technologies for identification, location sensing, and tracking1-5. The purpose of object localization is to estimate the absolute or relative location information of that object along with given observations and spatial relation between that object and known references by the localization system6-7. Global Positioning Systems (GPS) has well met the need for outdoor location sensing and has great value in determining the position of the mobile reader, referred to later as user, with centimeters accuracy8-9. However, when it comes to indoor areas, GPS is not reliable due to poor reception of satellite signals. In addition, GPS is still expensive for deployment to automate tracking of individual material items10,11.

A wide range of technologies were used for indoor location sensing such as ultrasound solutions12, Infrared-based solutions13, and ultra wide band (UWB)14. Localization technologies depend mainly on calculating the location based on signal measurements. Signal measurements used for that purpose are Received Signal Strength Indicator (RSSI), Angle Of Arrival (AOA) and Time Of Arrival (TOA)15,16. The signal strength has close relationship with distance between the sender and receiver.

RFID Technology is also used in this respect17,18. Li and Becerik-Gerber19 conducted a comparative study for the different indoor location sensing technologies taking into consideration the following factors: accuracy, affordability, line of sight, wireless communication, context independence, on-board data storage, power supply, and wide application in the building industry. Based on that study they concluded that RFID technology considered as the most suitable indoor location sensing technology. Choi20 arrived at the same conclusion; stating that passive Ultra High Frequency (UHF) RFID based localization
overscomes the drawback of conventional indoor localization systems such as high cost of installation and maintenance because of the relatively low cost, the absence of a power source, and lightweight of the passive RFID tag. This would justify the applicability of the technology for construction industry, which has a dynamic work environment. Most RFID localization literature focuses on deploying active RFID tags for indoor and outdoor environments. However, active tags are expensive and have limited life time (5-10) years.

Localization based on signal strength measurement has two main advantages; lower cost and simple implementation. Three major methods have been developed to locate a target using that technology; Triangulation, Proximity and Scene Analysis. Triangulation is a technique of determining the location of an object, based on geometrical properties and mathematical formulation. Triangulation determines the position of an object by measuring its distance from multiple reference positions. When the localization algorithm knows at least a set of three distances from different receiver, the algorithm can draw three circles, the radius of a circle is the measured distance, and the center is the known position of the signal receiver. The intersection of three circles determines the expected signal source's location. The Proximity method requires the measurement of the nearness of a set of neighboring points, which have fixed and known location, and are close to the target. The measured nearness, along with the corresponding known locations, are used to estimate the location of the target. Thus, the proximity technique guarantees the most simple and easy implementation for object localization.

This paper presents an indoor location identification methodology using low cost UHF passive Radio Frequency Identification (RFID) for construction projects. Two RSSI based localization methods are used (Triangulation and Proximity). A recently constructed project is considered to compare the results obtained from Triangulation and Proximity on construction job sites. Unlike the methods presented in the literature, which were focused on built facilities and not construction jobsites, the proposed methodology enables useful applications during construction and subsequently upon completion of construction to support facility management activities.

**PROPOSED METHODOLOGY**

In the present study, UHF passive RFID technology is utilized for capturing spatial data of indoor operations. The purpose of indoor location identification using RFID is to estimate the relative location information of the mobile site personal (the user) along with given observations of input and spatial relation between the user and a set of known references by the localization system. "Super-distributed" tag infrastructure approach is proposed. In this approach, a number of low cost passive RFID tags are distributed on the jobsite, and the mobile user carries the RFID reader. Each passive RFID tag is used as a reference point with known location (LANDMARK) within a predefined zone. In this study reinforced concrete columns, shear walls and wall edges were used as landmarks. The known locations of reference tags are used to estimate the location of the user, based on RSSI received from these tags. The indoor construction work-active area is divided into exclusive zones for tracking.

Figure 1 illustrates the process of deploying RFID reference tags, which start with assigning RFID reference tags to each zone’s landmark. Afterwards, for each reference tag the user should identify its coordinates (xi,yi) and store all this data in RFID database. This step is performed one time per floor and is used as input for location identification. Locations of reference tags are identified with subscript (i) and the location of the user is identified with subscript (j). Reference tags are used identify the user stationary location as shown in Figure 2. The user at a given location operates the RFID reader at time t and captures the signals received from the tags in that location. This process is then repeated at a set of time intervals, referred to here as Δt. In the field experiments, Δt ranged from 15 to 30 seconds. To ensure the use of signals from related reference tags only, a relational database was developed to filter these tags based on their respective IDs. Due to space limitation, the database will not be described here. Processing of the data captured is, using either the proximity method or the Triangulation method, is depicted in Figure 3.

Triangulation method requires a path loss model to convert RSSI to distance (D). The model was developed using 6704 data sets of laboratory experiments. Each data set consists of a number of signals captured at a specific distance. Linear regression was carried out using the average of the capture signals’ strength and the associated distance. Distance (D) was varied at an interval of 10cm. The developed relation is represented by Equation 1.

\[
\text{RSSI} = -6.182D - 32.68 \quad \text{Equation 1}
\]

The distances generated using Equation 1 were used to determine the location based on the Triangulation method described earlier. In case the intersection is not at a point, the center of gravity (C.G.) of the intersection area is used instead. The Proximity
method was also applied. As stated earlier, the Proximity method uses Received Signal Strength Indicator (RSSI) as a weighting method to express how near the reader to the reference tags. RSSI is a measurement of the power present in a received radio signal. Therefore, the higher the RSSI number (or less negative in some devices), the stronger the signal is, which means that the user is more near to that tag. The readings collected for each reference tag were averaged and converted into related weight \( W_i \), which represents how much closer the reader is to that tag. Using Equation 2, the coordinates of the user \((X_j, Y_j)\) are calculated. For example, Figure 6-a shows that the user stands in zone one and is surrounded by three reference tags having coordinates \((x_1, y_1)\), \((x_2, y_2)\) and \((x_3, y_3)\) and corresponding averages of \(\text{RSSI}_1\), \(\text{RSSI}_2\) and \(\text{RSSI}_3\), respectively. Using Equation 1, the system automatically calculates the user location \((X_1, Y_1)\). The developed database will not be described in this paper due to space limitations.

\[
X_j = \frac{\sum_{i=1}^{n} x_i W_i}{\sum_{i=1}^{n} W_i} \quad \text{and} \quad Y_j = \frac{\sum_{i=1}^{n} y_i W_i}{\sum_{i=1}^{n} W_i} \quad \text{Equation 2}
\]

FIELD EXPERIMENTS
To validate the proposed method and for demonstrating the feasibility of employing the components, methods, and technologies, field experiments conducted on a case study were applied on construction jobsite of the Center for Structural and Functional Genomics at Concordia University (Figure 5).
The main RFID hardware components used in the case study (Figure 6) are RFID mobile reader, RFID encapsulated tags, RFID label tags and RFID labels tag printer. RFID hardware could collect data in dirty, harsh, hazardous conditions. For example, the encapsulated RFID tag used, could work in temperatures ranging from -40°C to 66°C cost up to $5 per tag. Regarding its memory size it has a capacity of 512-bit-on-chip. In addition, RFID mobile readers could work under similar harsh conditions such as could work in temperatures ranging from -15°C to 50°C, protected from dirt, dust, oil, other non-corrosive material, and splashing water. The passive RFID tags used in these experiments were printed RFID labels, which cost a couple of cents each, RFID labels tags. The read range for encapsulated tags are 5m for and 3m for label tags (Intermec, 2012).

Five test beds were setup at different locations and different construction time span (Table 1). Experiments were conducted on the test beds to compare the results obtained from Triangulation and Proximity algorithms as shown in Figure 7. The figure shows the setup of the test bed, location of RFID reference tags, the user actual location and the estimated location using Triangulation method and Proximity method. Table 2 and figures (8, 9 & 10) show the statistical analysis for the results and the accuracy in meter for the all experiments and the performance for each algorithm for each test bed. Utilizing this methodology offers 1 m mean accuracy for triangulation and 1.65 m mean accuracy. Nevertheless, the experiments yielded 100% accuracy for identifying the correct zone in all test beds, which proves the feasibility of this procedure to be applied in construction jobsites.

Table 1. Characteristics of test beds

<table>
<thead>
<tr>
<th>Test Bed #</th>
<th>Test Bed 1</th>
<th>Test Bed 2</th>
<th>Test Bed 3</th>
<th>Test Bed 4</th>
<th>Test Bed 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Samples</td>
<td>418</td>
<td>494</td>
<td>451</td>
<td>729</td>
<td>438</td>
</tr>
<tr>
<td>Location</td>
<td>(3rd Floor)</td>
<td>(2nd Floor)</td>
<td>(3rd Floor)</td>
<td>(2nd Floor)</td>
<td>(3rd Floor)</td>
</tr>
<tr>
<td>Covered Area (m²)</td>
<td>75.24</td>
<td>75.24</td>
<td>75.24</td>
<td>108</td>
<td>120</td>
</tr>
<tr>
<td>No. of Deployed Tags</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>25</td>
<td>33</td>
</tr>
</tbody>
</table>
CONCLUSION

This paper presented a low cost location estimation method for indoor construction environment. The proposed method utilizes passive RFID technology for capturing spatial data of indoor construction operations where Global Navigation Satellite System (GNSS) cannot work. In this study, the work-active area is divided into exclusive zones and each zone is spatially covered by a number of passive RFID tags. Two different algorithms (Triangulation and Proximity) which utilize RSSI signal measurements are used to estimate locations of interest onsite. The developed methodology was applied to a recently constructed laboratory facility in Montreal, Canada. The results are presented and compared for different 5 test beds at different construction time intervals. The field experimental results show mean error of 1m for the Triangulation method with a standard
deviation of 0.4m and a mean error of 1.76m for the Proximity method with a standard deviation of 0.5m. The accuracy was 100% in zone detection, which is higher than that achieved in an author’s earlier study using KNN algorithm (e.g. 90%)\(^9\). In view of the findings of this study, the developed method can be used efficiently to capture and process sensed data to support near-real-time decision-making, timely tracking of the project status, proactive safety monitoring, and, subsequently, operation and maintenance of constructed facilities.

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Self-growing Motion Mechanism for Inspection and Maintenance

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Purpose An inspection and maintenance system is essential to obtain a proper and stable construction. However, internal inspection and maintenance of the inner parts of pipeline are difficult to conduct. Force effects should be eliminated to accurately inspect the state of a pipeline. This paper suggests a self-growing mechanism (SGM) which focuses on a minimization of force effects compared to previous progress maintenance methods. Method SGM mimicks the motion of amoeba, a protozoan, as a growing unit. It is shaped like a reversed hose. The SGM represents gelation and isolation of the amoeba; the inside skin is fixed outside and fluid is injected. In this way contact force is minimized so as to be negligible. By passing through injected fluid, the SGM acts as a buffer. Nevertheless, there is a limit to the use of this instrument for maintenance due to the drift of the upper section of the growing unit. To overcome this and expand the field application, the SGM was equipped with auxiliary equipment called install-base, this is composed of three rings. Bundling several units was also considered. This can give SGM direction by differential fluid injection to each unit, and facilitates progress through the curved paths. Results & Discussion SGM allows only contact force on the surface, similar to amoeba movement. This can be described as the contact which occurs when a rolled surface unfolds. SGM can help in the maintenance process of highly hazardous or unreachable spots, such as nuclear power plants, pipelines, and so on. It is best suited for highly sensitive environments. SGM is also promising in combination with inspection and maintenance of constructions with field endoscopy; it can provide medical checkups or remedies innovatively. Moreover, it is expected that SGM, unlike previous methods, can more accurately carry out maintenance of gradually downsized applications.

Keywords: self-growing, inspection and maintenance, pipeline, minimization of contact force

INTRODUCTION Recently, there are increasing infra constructions necessary to human life. Especially, needs of various pipelines such as for urban gas, sewage facility, chemical plants, and nuclear power plant and so on has been increased. According to this situation, importance of inspection and maintenance for pipelines is emerged. However, it is more difficult to carry out internal maintenance for pipelines because of access limit to operation spots than other processes. To overcome this point, a number of motion mechanisms for intelligent inspection and maintenance have been developed.

Previous motion mechanisms can be classified into many forms: wheel type, crawler type, legged mobile type, and inchworm type.

There was the simply proceeding method to use wheel. More practical design utilizing wheels has been also proposed, one of which is a micro robot driven by the principle of screw. The design is composed of main body and two tires and adopts proceeding along spiral trajectories on the inner wall. Motion mechanism based on inchworm type was suggested, one of mechanism can contribute to remote distance progress of system by friction effect as introducing friction rings. Other design with Shape Memory Alloys (SMA) as an actuator provides stable and accurate locomotion in way to alternate clamping with moving modules. Some researchers have also proposed different motion mechanism designs for inspection and maintenance of pipeline. An example of designs is called as mechanical adaptive in-pipe robot. It can be applied to various size of pipeline due to employing elastic wheeled legs and driving module which feature tri-axis differential velocity mechanism. The other legged type design was also studied: walking micro robot. Although numerous motion mechanisms are developed currently in order to improve efficiency of inspection and maintenance, constructions under inspection and maintenance operation are unable to
avoid a force effect caused by proceeding characteristic and usage of instruments for the task. When conducting inspection and maintenance of pipeline, as to detect the state of line accurately, it is necessary to eliminate force effects. The reason of this fact is that force effect can be the problem in respect to point which the inspection and maintenance is originally aimed at the overall improvement of the system. To satisfy the purpose of inspection and maintenance and take appropriate actions to obtain reasonable state of systems, the conditions obtained from operation should explain the system correctly. Unless getting out of a force effect, operation findings will not the present state but the state result from force effect. Because, at highly hazardous or highly sensitive environments, this can act as critical factor, improvement in inspection and maintenance technique is required.

This paper suggested the motion mechanism focused on the minimization of force effects in comparison with previous mechanisms for inspection and maintenance. As reducing force effect, this mechanism can find state of system accurately. It is named as the Self-Growing Mechanism (the SGM).

This new motion mechanism is based on the characteristic of amoeboid movement and liana’s growing. It has a strength applying at most contact force on relative surface. Through this paper, from basic concept of the SGM as new mechanism to ideas for auxiliary equipment required to realize actual progress will be presented. Finally, the experiment of moving forward was carried out by making prototype for the SGM.

**FOUNDATION OF THE SELF-GROWING MECHANISM**

1. **Bio-mimetic**
   The Self-growing mechanism is based on biomicetic: specifically, a protozoan organism and a liana.

1.1 **Protozoan mimetic**
   The amoeboid movement typically observable in an amoeba as a protozoan organism differs from traditional progress methods. A pseudopodium, an organelle for motion, is temporary processes of cell bodies. The basic components of the amoeboid movement are a gelation and solation phenomenon in amoeba body. Amoeba consists of ectoplasm and endoplasm. Ectoplasm exists as gel state inside thin pellicle called as Plasma lemma, and covers endoplasm in a state of sol. Endoplasm moves forward continuously, getting near the head of body, is converted into ectoplasm through gelation. Simultaneously, at the rear, ectoplasm is solated and complements endoplasm. That is, gel solates and goes into endoplasm region at the rear part of the body, and sol gelates and goes out to ectoplasm region at the head. These gelation and solation make whole amoeba body proceeding. Actually, amoeboid movement is similar to a spreading phenomenon of oil on water, so that the surface tension of the amoeba-surface interface is less than the water-surface interface when spreading. There are also a number of facts fully established which show conclusively that surface tension applied due to amoeboid movement plays a very insignificant role. The SGM adopts amoeboid movement in order to aiming at lowering the force effect on the surface within the framework of protozoan mimetic.

1.2 **Plant mimetic**
   A liana is commonly name to explain various plants which grow along trees as well as other means of vertical supports without standing itself. Its growth has characteristic climbing according to standard surfaces or supports located at core section of progress. Standard supports decide the direction of growth as being a sort of guidelines. The SGM adopts a liana’s growth characteristic so as to aim at setting the direction of progress and carrying out the required operations along the given path within the framework of plant mimetic.

2. **Correspondence of the SGM to the mimetic objects**

2.1 **Protozoan mimetic**
   The SGM as motion mechanism can proceed from core element called growing unit. The relationship between the progress of growing unit and the amoeboid pseudopodium movement is described in fig1. In the SGM, the growing unit playing the role of circulative ectoplasm and endoplasm is fueled by fluid injection. The difference of the SGM with the amoeboid movement at here is that the growing unit is not circulating and fixing external edge arranges the location adjusting proceedings.

2.2 **Plant mimetic**
   The SGM is modeled from a liana’s growth characteristic that it can go along the given path under the environment as guidelines.
DESIGNS FOR THE SELF-GROWING MECHANISM

1. Configuration of the SGM

The SGM is composed of several components in order to proceed. Composition of the SGM can be sorted to main and supporting parts.

- Main parts: growing unit, air pump as source for proceeding
- Supporting parts: install-base, Supply and Withdrawal(S/W) module, bundle for steering

There is described each briefly as following.

1.1 Growing unit

This paper suggests the new concept of a method of progress from protozoan and plant mimetic. The purpose of this study is to develop and apply the motion mechanism differentiated from previous ways. To achieve the goal, it employs the growing unit as key technology. Growing unit which shape is like reversed hose represents progress as growing gradually by fluid injection (fig3).

1.2 Install-base

The growing unit is gradually lengthened during proceeding and its upper section is continuously shifted. However, there should be space for taking the instrument needed to particular task. For that reason, the SGM equips the auxiliary equipment called install-base, composed of three rings to overcome the drift of upper of unit and obtain stably fixed position independently of drift.

1.3 S/W (Supply and Withdrawal) module

A capability of going forward/backward is essential for operation. Therefore, to add to going forward by growth of unit, S/W module is introduced for going backward.

1.4 Bundle for steering

The solution improving progress along the given path is to set up the direction of growing unit towards destination. Realization of steering utilizes the set of several growing unit. After making a bundle, each unit is supplied with differential fluid source.

2. Strength of the SGM

Even if many studies of motion mechanism for improving efficiency of maintenance have been conducted, they are not able to overcome inevitable force effect as proceeding. On the other hand, the SGM is superior with respect to minimization of force effect on the relative surface. Additionally, due to fluidic resource for growth, the SGM has buffer effect in itself. Because it is able to minimize friction factors, the suggested mechanism is termed the self-growing method distinguished from the previous.

3. Auxiliary equipment for installing instrument

Realization of the SGM only based on protozoan and plant mimetic has some limitations. Maintenance system can load instrument for operation so as to apply the SGM in many industries, go forward or backward, and alter direction for progress. Thus, auxiliary equipment was considered.

3.1 Install-base

Progress of the SGM is possible when outer edge of the growing unit is fixed and there is injection of fluidic source inside the unit, as if amoeboid movement. The feature of progress is so similar with circulated amoeboid body that there is at most contact force on relative surface. Although the SGM has the minimized force effect as strength, there are limitations for applications in fields due to drift of the upper section of unit. That is, it is not able for the SGM itself to equip the instrument. Therefore, Install-base is considered as auxiliary equipment making up for the functional defect. It is required to be located on the upper surface of unit, not drifting away.

- Structure of the install-base

The idea about Install-base starts from simple constraint structure. Install-base has 3-rings as components. The degree of constraint between each ring...
adjusts appropriate positions and function of install-base. The fig.5 shows the arrangement of 3-rings. From up of growing unit, the rings are numbered as 1-, 2-, and 3-ring. The 2-ring is inside the growing unit, and is bound by 1- and 3-rings. Restriction is built by making the outside diameter of 3-ring bigger than the inside diameter of 2-ring and connecting 1- and 3-rings. The upper section which 1-ring is located offers the base space for equipping the device needed in operations.

4. Auxiliary equipment for forward/backward and steering motion

4.1 Supply and Withdrawal module
Above all, forward moving is accomplished already. However, proper measures for backward moving are not made yet. For this reason, additional supplement is added. Forward/backward movements are matched to supply and withdrawal of the growing unit. It is located on the top of unit and does not interfere with the function of install-base. Its name is Supply and Withdrawal module.

4.2 Bundle for steering
System has to move smoothly along the given path to approach the destination. Therefore, the condition which the SGM has to possess is setting up direction of proceeding.

To steer, a bundle is composed of several units. Differential fluid injection to each unit is the key for direction of the SGM. A change of direction happens as much as difference of injected fluid. The more important thing is stable composition of bundle because unit-set is separable when proceeding. Especially, because there can be amplification of gap between units in matter of a long distance progress, it is necessary to maintain consistent bundle of units.

4.3 Establishment of forward/backward and steering motion

- Rail-embedded growing unit
For S/W module and bundle for steering, rail-embedded growing unit is used. This is made from original plane unit by installing rails internal/external surface of unit. Its shape can be confirmed in fig.6. External rails are utilized to compose bundle and become path for 3- and 1-rings of install-base, while internal rails conduct a role of guide for 2-ring.

- Connection for bundle
Since one independent unit only cannot set up direction, special method for connecting several units is needed. For this aspect, rail-embedded growing unit as well as wheel-set used for connection of units is introduced.

![Fig. 6. Rail-embedded growing unit](image)

![Fig. 7. Connection for bundle](image)

![Fig. 8. (a) Conceptual auxiliary equipment, (b) Conceptual auxiliary equipment without growing unit](image)

The wheel-set can not only move along the rail, but also prevent breaking away from rail, owing to a pair of two wheels. A pair of wheels per a growing unit is element for a bundle, which establishes the one bundle-set by combining other pairs.

- Concept diagrams of auxiliary equipment
The fig. 8 is concept diagram of installed auxiliary equipment. In order to explain equipment easily, the configuration of one unit connected with bundle-set and independent auxiliary equipment except unit are described in fig.9 (a), (b).

The 1-ring is connected with 3-ring by centrally passed rod and 1- and 3-rings together restricts 2-ring’s separation. Moreover, as giving the wheel more play on the external rail of the unit, minimizations of position change as well as jam of unit in equipment are facilitated during the 1-ring is on the unit surface.
Bundle of 3-units set up direction of progress by provision of fluidic source. At that time, if connection is completely solid, it can cause inefficiency of setting up direction and hindrance to progress. The solution for these problems is to assign elasticity to the connection between unit and bundle.

The degree of going forward or backward of the SGM is determined by the degree of supplying or withdrawing growing unit. Therefore, when making system including the SGM, it has case for storing growing unit. Adjusting growing unit will be carried out by motor actually.

While, as moving forward, fluid injection produces the growth of growing unit, as moving backward, limited fluid injection maintains the shape of unit and withdrawal of unit is conducted.

## EXPERIMENT FOR THE SELF-GROWING MECHANISM

For the SGM based on features of amoeboid movement and liana’s growth, prototype was made. Using the prototype, experiment for forward going performance was carried out. The information about experiment can be categorized as following.

- Experiment about forward going performance of one growing unit, providing fluidic source by pump
- Experiment about forward going performance of one growing unit with install-base
- Later planned experiment about forward/backward and steering motion

### 1. Hardware requirements for the prototype of the SGM

- Air pump: the power source for proceeding of growing unit
- Material for growing unit: in order to maximize growth performance of unit according to its material, ad-balloon is selected finally. For experiment, vinyl unit was used.
- Case: assign the space of fixing and storing growing unit and fluid path
- Install base: by using prototype, experiment was conducted
- Valve: determine the degree of going forward as the degree of opening or shutting

### 2. Experimental plan and result of forward moving performance

#### 2.1 Experimental plan

- Progress of growing unit by adjusting air pump and valve
- Find forward going performance after equipping install-base

Fig. 10. Elasticity assigned to the connection between unit and bundle

The ultimate purpose of this experiment is to grasp the SGM’s performance of going forward.

#### 2.2 Experimental result

Fluid (at here, air) as power source is transfer to internal growing unit through case by adjusting valve. Continuous growth is derived by provided unit stored inside case by fluidic push. Fig.10 shows prototype of install-base and experiment of forward going performance.

This leads to confirmation of basic forward going of the SGM. If additional experiments about forward/backward and steering motion are made, the SGM can be developed as more complete moving mechanism.

## CONCLUSION

This paper introduces the Self-Growing Mechanism which is the method minimizing the force effect on the surface in order to conduct inspection and maintenance operation effectively by finding the current state of subject accurately.

The SGM is motion mechanism based on protozoan and plant mimetic. Due to using fluid as resources, the SGM has buffer effect in itself. Furthermore, progress by the growth of growing unit generates at most contact force as if a rolled surface is getting unfolded. In previous motility mechanism, force effect is inevitable element. This point can be problems especially in sensitive environment because the
inspection results may have highly deviated distribution according to effect from exterior conditions. Therefore, the SGM can be superior mechanism which reduces damage/deformation of surface and conducts tasks in sensitive environment. The SGM can equip the instrument for inspection and maintenance by install-base and can not only move forward/backward but also set up direction of progress through S/W module and bundle connection. With this, the SGM becomes the great means of inspection and maintenance to apply various industries.

Concretely, the SGM has sufficient potentials to enter tunnel-, pipe-maintenance, and endoscopy field. Although inspection and maintenance inside tunnels is essential for traffic safety, it is in poor conditions. That is, workers in tunnel are exposed to respiratory problems and related industries become job which most people avoid getting into. Moreover, perhaps the vicious circle of this fact brings about a manpower shortage or aging of manpower. The SGM can be utilized here for inspection and maintenance by adjusting the system at outside. Another example is pipe-maintenance similar to tunnel-. Because, for circulation of regional heated-water, double insulating pipe is laid under the ground, it is difficult to check damage of grid after construction of line. The SGM is expected as alternative plan for detect damage of grid after construction of line. The SGM has sufficient potentials to enter tunnel-, pipe-maintenance, and endoscopy field.

ACKNOWLEDGEMENT
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References
Non-destructive GPR evaluation of underpass arch-shape structures

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Purpose In recent decades, road inspections have used automated vehicles that integrate LiDAR, GPR, and IRI measurements. GPR-data provide valuable information—typically about the pavement thickness—for road assessment. The aim of this work is to test the GPR-system to provide geometric information about underpasses of roads, principally related to the depth and span length. Method Both high and low frequency antennas (500 and 200 MHz) were used to determine the most appropriate survey methodology for our purpose. This technique was used to detect the different layers of an arch structure. To validate the method, GPR-data were compared with the ground-truth data provided by a mobile laser scanner. Results & Discussion The GPR results showed the potential of the system to obtain information about subsurface structures, and the arch geometry (depth and span length) were defined. However, the heterogeneity of the backfill over the arch made it difficult to use the field data we obtained. Finite-difference time-domain (FDTD) modeling was used in this work to understand the response of the radar wave and to assist in the data interpretation. The synthetic models were built from the orthoimage provided by laser scanner, defining the structure in fine detail, which resulted in large scale and more realistic models. Laser scanner errors in geometric measurements were lower than the 6 mm of the laser used as the ground truth for this work. By exhaustive interpretation of the field data—once they were analyzed through modeling—we found that the GPR-data are consistent with the laser scanner data and open the possibility of using GPR-information to obtain the geometry of subsurface structures for road inspections. This information could be useful to make structural calculations and predict critical failures.

Keywords: ground-penetrating radar, laser scanning, road inspections

INTRODUCTION

The highway Ourense – Celanova will become during the next years one of the main roads of inland Galicia (Spain) that will result in a quick connection route to the cities of Northern Portugal. This motorway is projected as a public – private partnership between the regional transport administration (Xunta de Galicia) and the construction companies Copasa SA and Exarco SA. This partnership includes private funding for the construction works and subsequent payment by indicators of management efficiency. The infrastructure has a number of underpasses for the passage of wildlife animals, person and agricultural machinery. The underpasses consist of two reinforced concrete voussoirs placed on two small concrete walls (Fig.1). For each set of voussoirs there are three joining points, two between the walls and the voussoirs and one between the both voussoirs and the top of the structure. These underpasses suffer significant mechanical stress during construction and service life that must be monitored. In the last decades, there has been a continuous increase in the use of non-destructive testing (NDT) to evaluate civil engineering structures. This work presents the use of non-destructive geodesic and geophysical techniques for the assessment of underpass arch-shape structures. Ground penetrating radar (GPR) was chosen since the method is a non-destructive geophysical technology that provides quantitative information about the subsurface structures, which cannot be inspected with the traditional optical technologies (i.e. total stations, LiDARS).GPR is one of the most frequently recommended NDT methods on civil engineering because it is a relatively quick technique that gives an overall qualitative internal image of the shallow subsurface. It provides high penetration depth and precise horizontal and vertical positioning. These two-dimensional images, called radargrams, are XZ graphic representations of the reflections detected. The X axis represents the antenna displacement along the survey line, and the Z axis represents the two-way travel time of the pulse emitted (in terms of nanoseconds). If the time required for the electromagnetic pulse to go from the transmitting antenna to the reflector into the ground and return to the receiving antenna is measured and the velocity of this pulse in the subsurface medium is known, then the position of the reflector can be determined. However, to date there have been few published studies on the dimensional and structural analysis of subsurface structures, probably because NDT on masonry civil engineering structures with GPR is a relatively new subject since the 1992s as well as the geometric and interpretational difficulties of these complex environments, with some notable exceptions. The analysis and interpretation of GPR data can be
complicated since many factors can adversely affect GPR waves, including ringing noise, diffraction events and reflection multiples. Numerical modelling has become an interpretational tool that can be used to compare processed GPR data to models to understand the radar-wave propagation phenomena and to facilitate GPR data interpretation. When more sophisticated interpretations are required, the finite-difference time-domain (FDTD) technique has evolved into one of the most popular advanced modelling tools for simulating the propagation of the GPR waves in different media. This modelling method allows for the extraction of subtle information from the real data, such as diffraction patterns and the presence of reflection multiples.

To analyze the viability and effectiveness of GPR this work includes the use of LiDAR methods. Three-dimensional laser scanning is the most evolved technology in the metric documentation of built up structures mainly due to the high rate of measurement over the structure surface with millimeter accuracy and incorporation of texture information of the objects to the metric laser data. The metric information obtained by LiDAR allows calculating the most appropriate average velocity of the radar-wave for different media. Moreover, the precise geometric data provided has shown its capabilities as inputs to create large scale and more realistic FDTD numerical models.

**METHODOLOGY**

This work aims with the dimensional analysis of underpass arch-shape structures by means of NDT techniques. A GPR data was carried out to obtain inner information of the structure and, for target identification, the approach included the use of mobile LiDAR, which provides more detailed information about structural geometry and shapes. Moreover, to improve interpretations of the field GPR data, FDTD simulations were built from the accurate geometry provided by LiDAR.

**Ground penetrating radar**

The GPR survey was conducted using a RAMAC GPR system from MALÅ Geoscience. For the purpose of this work, both high and low frequencies were chosen (500 and 200 MHz, respectively). These frequencies were selected as the most optimum due to its compromise between penetration and resolution. The 500 MHz frequency provides on the order of 6 m in depth penetration (under optimum conditions) and a spatial resolution of 5.75 cm. Nevertheless, although the 200 MHz frequency provides a spatial resolution on the order of 14.25 cm, the depth penetration results in about 12 m. The value for spatial resolution was calculated considering an average radar-wave velocity of 11.5 cm/ns, as reported in the literature for dry limestone soils.

GPR profiles transverse to the arch structure (in the direction of traffic flow), were gathered twice: First dataset was conducted with a biestatic 200 MHz unshielded antenna. This frequency was selected as low enough to reach the entire structure. The offset between transmitter and receiver antennas was set to 0.6 m (Fig. 2). The profiles were carried out using the common-offset-mode through the surface of the highway over the underpass. The survey parameters assumed were 10 cm trace-intervals, total time window of 200 ns, and 449 samples per trace.

The second dataset was conducted with the biestatic 500 MHz shielded antenna to obtain more detailed information of the shallower backfill material over the structure. The survey parameters selected were 5 cm trace-intervals with a 75 ns total time window and 519 samples per trace. In this case, to measure the profile length, the GPR antenna was mounted on a survey cart with encoder (odometer wheel). The GPR data collected was processed with ReflexW v.5.6 software to correct the down-shifting of the radar section due to the air-ground interface and to amplify the received signal, as well as to remove both low and high-frequency noise in the vertical and horizontal directions. The processing sequence applied was: time-zero correction, dewow filtering, gain application, spatial filtering (“Subtracting average”), and band-pass (“Butterworth”) filter.
LiDAR

Geometric data were acquired using a mobile LiDAR from Optech Lynx (Fig. 3). The system integrates a navigation GPS/INS system from Applanix (POS 520 - 2 GPS antenna), 2 LiDAR scanners from Optech and 4 digital cameras from Jai (BB 500GE). The metric characteristics of the Lynx system are shown below:

- Maximum range: 200 m
- Range precision: 8 mm (1σ)
- Absolute accuracy: 5 cm (1σ)
- Scan frequency: 80 – 200 Hz
- Scanner field of view: 360º
- Laser measurement rate: 75 – 500 kHz

Mobile LiDAR survey began and finished with the acquisition of 5 min of GPS data in an area with small PDOP (high GPS precision). The complete time of the survey was 14 min. Scanner and photographic data are only taken while the van is moving to avoid the excess of data. The synchronization of the data from the different sensors of the mobile unit is achieved using the time stamp and the PPS of the GPS/INS system. A total of 240 million of geometric points were acquired during the survey.

The data processing is performed using Applanix POSPac and Dashmap software. The first one corrects the GPS information using a RINEX file from a base station. In addition, combines, using a Kalman filter, the data from the GPS with those obtained from the inertial navigation system (INS) and distance measurement indicator (DMI). The corrected trajectory file exhibits a precision higher than 2 cm in X Y and higher than 4 cm in Z.

Dashmap combines the range and angle information obtained from the Optech scanners with the trajectory information from PosPAC.

The point cloud obtained will be managed using the QT Modeler software in addition to Matlab and AutoCAD softwares to obtain the images (transversal sections) to be used for numerical simulation.

FDTD modelling

The overall objective by using numerical simulation is to assist in the interpretation of the processed field data acquired by GPR. The synthetic results can supply important additional information for the advanced interpretation of GPR data by rendering the complex pattern of reflections obtained. This allows identifying clutter reflections from the field data and extracting subtle interpretational information such as the timing, presence of reflection multiples, and target material properties.

To construct the synthetic models, the GprMax v.2.0 software was used, which is an electromagnetic wave simulator for GPR using the FDTD method. Simulating the GPR response from a particular target using a FDTD method, Maxwell’s equations require to be solved with the appropriate initial and boundary conditions and the adequate description of the material properties. The precise geometry provided by LiDAR methods was used to elaborate on the FDTD modelling using the Matlab software.

Knowing the real geometry of the underpass arch-shape structure can provide useful information towards the creation of more realistic synthetic models. The need to discretize the volume of the problem space and the staircase approximation of curved interfaces to the real boundary result in an excessive computer memory requirements as well as large execution time. To reduce the computational time, the synthetic models were elaborated using a mixed model of parallelization in GprMax based on a hybrid message passing interface (MPI) and open multi-processing (OpenMP) parallel programming in GprMax software.

The synthetic models were created with a small spatial-step equal to 35 mm, and the excitation pulse was a Gaussian of 200 MHz centre frequency. The trace step and the total time window were 0.1 m and 160 ns, respectively, and were defined by 230 traces per sample. This approach encompasses the geometry of the arch in fine detail. The electromagnetic properties assumed for media characterization are shown in Table 1. These values were obtained from the published literature. Two different media were considered simulating the reality. Once the arch was placed, it was recovered by a compact layer until 1.5 m over the keystone (backfill 1), and a second layer (backfill 2) was used to fill until the road level (2 m more).

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity (Sm⁻¹)</th>
<th>Relative permittivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Backfill 1</td>
<td>0.001</td>
<td>6</td>
</tr>
<tr>
<td>Backfill 2</td>
<td>0.0001</td>
<td>7</td>
</tr>
<tr>
<td>Concrete</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. Electromagnetic properties for media characterization.
RESULTS AND DISCUSSION

Figure 4 shows the GPR data acquired with the 200 MHz unshielded antenna over the underpass in the transversal direction of the structure. Observing the radargram, it was possible to identify the reflection produced at the arch-air interface (red arrow), as well as the one due to different layers of materials used to fill the arch until the road level (white arrow). The orange arrow (4.5 m approximately) indicates the placement of a backfill until the haunch of the arch (between the springing and the keystone) to ensure the stability of the underpass structure (Fig. 1).

To determine the depth of the reflections identified, the velocity of propagation was set to 11.5 cm/ns, as reported in the literature for dry limestone media\textsuperscript{11}. For calculations, the difference pick application\textsuperscript{9} was used considering the wave travel-time difference from reflections at known distance (for example the air interface at the top and the one for the first layer). In this way, the depth of the arch’s keystone (from the road level) resulted on the order of 3.75 m (65.8 ns), and the depth of the reflection generated at the interface between different layers was 2.18 m (38 ns), which is comparable to the reality. Moreover, the arch’s span was estimated in approximately 12.0 m (whose real dimension is 12.8 m). In this case, using the velocity of propagation for concrete media (5.5 cm/ns)\textsuperscript{13}, the radius of the span was determined by adapting a diffraction hyperbola\textsuperscript{9} to the hyperbolic reflection generated at the arch-air interface.

On the other hand, the 500 MHz data collected have not revealed interesting details of the shallower subsurface over the underpass structure. Although the spatial resolution is greater than 200 MHz frequency, and differences in layer were identified (the white arrows in Fig. 5), the depth of penetration was not enough to reach the structure with the selection of a total time window of 75 ns. Under optimum conditions, this time window allows to reach until 4.0 m in depth considering a velocity of propagation 11.5 cm/ns. The first interface between different layers at about 2 m was even not detected. Reflections were recorded only until 1.75 m (30 ns) instead of the expected 4.0 m (75 ns), which could be most probably caused by a severe attenuation of the electromagnetic signal.

The result obtained from the mobile LiDAR is a georeferenced point cloud (WGS84 datum). This point cloud was managed using QT Modeler software (Fig. 6).

Finally, a transversal section of the point cloud is extracted from the point cloud (Fig. 7) to be used in combination with the GPR data. QT Modeler, Matlab and AutoCAD software is used in this step.

FDTD modelling was used to analyze and to understand the pattern of reflections obtained from the field GPR data. The synthetic model used for simulations was built from the CAD profile in Figure 7. Once the synthetic results were provided, they were exported to ReflexW software and filtered using a very similar processing sequence than that used for the field data.
Figure 8 shows the synthetic results generated, where relevant interpretational reflections were identified such as the hyperbolic reflection from the arch-air interface (R1), and the reflection caused by the dielectric contrast between the backfill layers used to fill the arch (R2), in addition to reflection multiples (R3).

**CONCLUSIONS**

The viability and effectiveness of the GPR was demonstrated when surveying subsurface structures in road inspections. Nevertheless, FDTD modelling was used to understand the pattern of reflections obtained and to assist in the interpretation of the field data. The synthetic models were built based on the accurate geometry provided by mobile LiDAR technology. This approach encompassed the underpass arch-shape structure in fine detail, and more realistic and large scale models were built using a mixed model of parallelization. Using a mixed model of parallelization, the simulation allowed the extraction of subtle interpretational information such as reflection multiples, in reasonable time.

The use of GPR can provide a solution for engineers engaged in creating or improving the processes and services related to the evaluation, rehabilitation and maintenance of on-road civil structures.

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**References**

Ultra-pervasive district monitoring for water leak detection

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Purpose One of the main concerns regarding integrated water resources management is related to the development of scalable monitoring and control systems for pro-active maintenance of water distribution networks. It is necessary for the availability of ultra-pervasive sensor-actuator networks to be deployed at the district level. The same technology is useful for several other applications involving sensors accrued from city to building scale. This paper deals with the design, development, and initial experiments of a first prototype of ultra-pervasive monitoring network for automated leakage detection in water distributions system (WDS). These pose technology challenges mainly generated by the need to transmit from underground. Method The availability of a new generation of ultra-pervasive communication and monitoring systems is a prerequisite for providing fine-grained, real-time monitoring data at district level, so that control policies can be applied in real-time. The sensing layer developed in the system object of this paper is intended for a dense deployment even underground. It is based on short-range battery-operated wireless networks, forming a mesh made up of end devices (sensors/actuators), routers/repeaters and coordinators/gateways. The coordinators/gateways –besides coordinating the network routing– transfer sensors packets to a host application enabling interconnection to fixed and mobile networks made available by the Telco operator. Because of this set-up the network can cover a large territory at low cost. It supports leakage detection algorithms, estimates leakage occurrence probability and pinpoints them. Results & Discussion First laboratory trials and preliminary onsite experiments show the feasibility of the approach and the potential for ultrapervasive communication through the network. Results indicate this system to be cheap and easily deployable alongside WDS.

Keywords: information technology, ultra-pervasive sensing, district monitoring, maintenance

INTRODUCTION
ICT-supported integrated water resources management for water supply systems has great potentials of ensuring higher water quality and longer network life-time, fewer water leakages and lower consumption levels. To that purpose, intelligent decision support tools must be fed by large scale and ultra-pervasive sensor-actuator platforms, hooked up with widespread telecom side communication networks. Optimal water resources management is one of the utmost and greatest 21st century challenges worldwide, because water resources are presently under stress. In fact, droughts have become more severe over the past 30 years and they are aggravated by concurrent demand from several domains such as agriculture, industry, domestic users and, additionally, inefficient water use. Several countries, including those located in Southern Europe, register low levels of pipelines maintenance, which are still based on budgetary restrictions rather than on authentic technical and economic considerations. This approach leads to a very low rehabilitation rate and does not allow for the assessment and management of risks. Finally, according to available studies, in some Southern European areas, leakage in water distribution networks still accounts for up to 50% (approximately 25% on average) of water entering the network. Moreover, spatially accurate leakage data are unavailable. Nowadays integrated water management systems, organized through modular and flexible architectures and adaptable to various situations, are under development. Among them, automated leakage detection of buried water supply systems is one of the most important services and asks for the availability of a large scale monitoring, communication and control networks, which should be used for data gathering and to feed the decision support models running on top, performing automated diagnoses. This poses the new great challenge of territorial integration of large scale embedded (multi-purpose) wireless sensor/actuator networks as interfaced to intelligent decision support models. With respect to real-time water management services, to date remarkable EU projects such as “Autoleak” (http://www.autoleak.eu/default.html) and “Warmer” (http://www.projectwarmer.eu/) are each oriented towards a specific focus: the former aims at the integration of existing advanced technologies for leakages pinpointing and the latter at creating a system for continuous monitoring of surface water quality. In the field of pipelines diagnosis, besides
traditional "craft" approaches such as acoustic rods and ground phones, nowadays leaks detection is carried out through specific systems, which must be kept deployed on site until enough data are collected, and their data subsequently elaborated for the final leaks localization. They require human resources for deployment, data collection and analysis. As it is a manual approach, it causes leaks to be pinpointed with a certain time lag and no intervention prioritization is had. In this framework, the field of water services is already waiting for an ultra-pervasive network. WaterWise project demonstrated the application and control of a low cost wireless sensor network for on-line monitoring of water distribution systems enabling remote sensing and prediction of pipe burst events but with limited spatial resolution. The usage of near zero power wireless sensor networks (WSNs) can increase the spatial and temporal resolution of operational data and thus address the challenge of near real-time monitoring. The WaterSense Project (http://www.projectwatersense.nl/?lid=en) is involved in the development of an integral decision support system for water quantity and quality management for a large area but with a relatively low spatial resolution, too. Hence long-life and low-cost (hence allowing high spatial density) self-powering or battery operated sensors' development is a relatively unexplored field. Their availability would allow the implementation of automated procedures based on already existing knowledge on leakage diagnosis: noise sensors pervasively deployed across water distribution networks would be able to immediately warn when new water spills are under formation or are likely to be present; the advanced data processing algorithms for cross correlation and pre-filtering would be able to pinpoint the failures positions. In this paper we present the first part of the system, conceived as an ultra-pervasive monitoring and communication network, designed so as to be interfaced and expanded through existing telecom infrastructures (e.g. phone cables) in order to cover very wide territories with the minimum usage of added infrastructure. The proposed ultra-pervasive network is made up of cheap, noninvasive, easy deployable sensors, whereas communication features shall be flexible, versatile and thus usable for a number of applications in order to reduce installation costs. Services shall be remotely operated and monitored in order to improve efficiency and keep real-time control of the whole system.

THE PERVERSIVE MONITORING SYSTEM
Automated leakage detection for the implementation of advanced maintenance policies is one of the many services made feasible by the availability of an ultra-pervasive monitoring and communication platform. Other functionalities have potentials to be included in a comprehensive management systems for water supply networks, such as:

- real-time control of correct operation and optimization of the systems, such as adaptive pressure, flow rates, and monitoring of chemical and physical indicators;
- intelligent modulation of operations aimed at the optimization of energy consumptions;
- bi-directional communication based on intelligent support systems, in order to align both the demand and supply sides, which should decrease peak demands and shortage time periods, as a consequence;
- quality of service improvement (e.g. real-time metering and adaptive pricing, advising customers through cost-benefit assessment).

Finally, the availability of such ultra-pervasive communication platforms, would extend its benefits onto companion fields of the smart town concept (Fig. 1), such as intelligent management of waste, parking, touristic routes, lighting, security, facility management etc.

In this paper not only a prototype of monitoring system has been developed, but it has also been customized to automated water leakage detection. The design of the communication logic's architecture was tailored towards a flexible structure, and making it easy to deploy (Fig. 2). A software interface will have bi-directional communication with the machine to machine (M2M) platform which is thought to potentially implement also the “Future Internet” concepts (distributed agents, workflow and orchestration and web services interface).

The ultra-pervasive network is composed by two layers that shall interface and interoperate:
1) short range battery operated wireless networks for connecting the high spatial resolution sensors and devices together and to the Short Range/Long Range Gateway;
2) long range network based on the Telco networks. It can be both Wire-line (xDSL and Fiber, phone cables, PLC through electric network) and Wireless (2G/3G/4G, WiFi).
It depends on the availability of existing infrastructures by the local Telco operators: sometimes a redundancy of choices is available and some other times they are constrained by the effective availability. Hence also the gateway will be manufactured differently according to the real on site situation. Short range high spatial resolution network shall be an ubiquitous battery powered low cost wireless sensor network capable of enabling two-way wireless communication for real time monitoring in water distribution infrastructure management: the ability to put a sensor anywhere, without wiring, allows easy network deployments and maintenance. The network devices are called: Coordinator/Gateway, Repeaters/Repeaters and End-devices (Sensors/Actuators). Technically, Coordinator/Gateway is a device that coordinates routing, aggregates sensor packets and transfer them to a host application enabling the interconnection to fixed and mobile networks. Repeaters/Repeaters are ultra-low power wireless transceivers that forward data to and from associated sensors or actuators and use an on-board radio to send the packets to neighboring routers. These pass the packets on to other routers and, in a series of “hops”, deliver the data to their destination. An end-device is made up of two main parts: a communication device and a measurement probe (i.e. accelerometer).

To be noticed that the proposed architecture allows information to be spread easily and using existing infrastructure, which is in fact economically efficient.

THE NEW CONCEPT OF AUTOMATED LEAKAGE DETECTION

At the bottom battery-powered noise loggers (equipped with accelerometers) are deployed along water pipelines: they perform a pre-elaboration of signals through a micro-processor and then forward the required messages to the closest routers through an 868 MHz transceiver. Repeaters are other battery-powered nodes, used to cover communication at the urban and extra-urban levels and scattered over wide territories. As depicted in Fig. 3, communication between noise loggers and routers passes through some repeaters, which are located close to noise loggers, whose distance depends on how deep they are buried.

The routers transfer their messages to the coordinator, which manages the network and interfaces to the widespread communication network, acting in fact as a gateway.

Two preconditions must hold in order for the previously depicted automated leakage detection system to be feasible:
- the system should automatically recognize and alert in (near) real-time when leakages are occurring;
- all the network’s devices, but the coordinator/gateway, must be battery operated, hence have very low consumption levels in order to guarantee long life of service (with minimum maintenance costs).

As far as the first item, noise loggers equipped with accelerometers will be deployed on pipelines to record and pre-process vibration levels, subsequently they will transmit an alert only if a leak is suspected and its localization is required. The pipelines will be accessed through existing inspection pits (generally located a few hundred meters apart) and the sensors will be connected to the ultra-pervasive communication network. Once acceleration measures are performed, embedded micro-processors will pre-elaborate the information collected, in order to transmit only compact data for post-processing that would allow for the server to work-out the leakage probability and localization.

As short range high spatial resolution network shall be a ubiquitous battery-powered and low cost wireless sensor network capable of enabling two-way wireless communication, easy network deployment and autonomy are compelling requirements. In this direction, a fully battery powered wireless network capable of guaranteeing extremely low
power consumption (as far as 0.05 mW) was developed through customization of the system manufactured by the company Smart Space Solutions srl. It maintains the same performance levels of standard wireless devices, such as conventional Zigbee, but operates in asynchronous mode, that is with no latency and with no timeslot restriction to communication and data throughput. At the long range level, existing mobile and fixed network (with several options, such as using existing telephone cables -e.g. twisted pairs- to power sensors) will be exploited, and will be part of further research steps. Instead this paper is focused on the development and testing of the short range communication module.

Leakage probability estimation
As soon as a water leakage takes place, in that same point vibrations and then a continuous noise are caused. They propagate along the pipeline, until they are faded out by damping, which in metal pipes requires very long distances. That is why the first step in leakage detection is generally recording noise levels at pre-determined positions of the pipeline, which is carried out preferably during the night, as other interferences are reduced to the minimum (i.e. low traffic, few human activities etc.). Equivalent noise levels (w.r.t certain reference noise level) are recorded based on acceleration data over a few minute wise time period, and then ranked according to their intensity, until distribution graphs (equivalent noise level vs. number of recorded levels) of the kind in Fig. 4 are worked out. Assuming that noise produced by leakages is always present and that noises are additive, the minimum noise level in the resulting distribution is due to the leak if it is present. When this minimum level is rather high (usually higher than 10 dB depending on the reference sound level), then a leakage is very likely (Fig. 4.a). Disturbances in the measurements are added to the leakage noise and thus affect only the spread of the distribution (Fig. 4.b): when they are sharp and the minimum level is rather high (usually higher than 10 dB depending on the reference sound level) then a leakage is very likely (case a in figure); the spreader is the distribution the less likely is the presence of leakages (case b in figure).

The “leak value” ($LV_{\%}$) is defined as the probability of a leakage taking place and is expressed as a percentage. Leak Value is computed as function of the 5% inferior quintile ($q_{5\%}$), because it represents how high noise levels are, and of the diagram’s spread (defined as $q_{95\%}-q_{5\%}$), because it represents how interfered the noise is. The general relationship is given as in the equation below and generally worked out from empirical samples performed in the laboratory, as reported in the following paragraph:

$$LV_{\%} = c_1 + c_2 \cdot q_{5\%} + c_3 \cdot (q_{95\%} - q_{5\%})$$

(1)

Leakage localization
If the probability of leakage occurrence is high, cross-correlation between two signals recorded by two noise-loggers placed on opposite directions from the area where the leak is generated, is used to pinpoint it. The basic concept is to measure how similar the signals are. Computation can be performed through the following relationship:

$$C_{s1,s2}(\tau) = \int_{-\infty}^{+\infty} s_1(t + \tau) \cdot s_2^*(t) dt$$

(2)

where $\tau$(tau) is the translation amount of the second function over the first. When the integral is computed, if the signals are similar there is a value of tau which maximizes the integral (Fig. 5a).

On the contrary, if the integral gives back a diagram containing no sharp peaks, it means the two noise loggers have received different signals, hence they have not been generated by the same source and a leakage is likely not present, or the generated vibra-
tion has been completely damped out. For that reason noise loggers are usually deployed at the corners of pipeline networks, so that each branch can be isolated and tested for leakage (i.e. confirmation of presence and estimation of distance). The system’s logic in this case works as in Fig. 5.b. Once cross-correlation is performed, given $D$ as the distance between noise loggers, $v$ the noise speed along the pipe (known from material, pipe thickness etc.), the estimated leak distance off the first noise logger is:

$$L_1 = \frac{D + v \cdot \tau}{2}$$

(3)

**DEVELOPMENT OF THE MONITORING SYSTEM’S PROTOTYPE**

The smart noise logger in Fig. 6 was thought to be permanently deployed on steel pipelines, taken in place through a magnet at the bottom of the external cylinder. Its components were chosen also to make it: cheap, low power, light, small sized, capable of pre-processing, having a high transmission range (from underground). Its main components are:

- one piezoelectric accelerometer type “BU-23173-000” by Knowles Electronics™ (USA), which has good and flat sensitivity until $10^3$ Hz with sufficiently low noise (Table 1);
- one PIC micro-processor;
- one printed circuit board with complementary electronic devices;
- two replaceable AA batteries;
- one external radio antenna;
- one magnet;
- one external cylindrical hard cover made by high density PE80 polyethylene, which has a 0.032m diameter, is 0.003m thick, 0.165m long (0.28 with the TX/RX antenna).

The used ultra low-power accelerometer provides a voltage signal proportional to measured acceleration.

![Fig.6. external view (a) and interior (b) of the prototypical noise loggers used for the experimental phase](image)

**Table 1. Datasheet excerpts of the BU23173 accelerometer embedded in the noise loggers**

This signal is converted to a digital value by the microprocessor after having passed a suitable anti-alias filter: the result is a digital 16 bit signal with 1024Hz of data rate.

In order to compute an equivalent noise level, a sequence of N digital values is acquired and converted to acceleration values $a_i$. Given a reference acceleration $a_0$, the microcontroller implements the following equation:

$$L_{eq}[dB] = 10 \log_{10} \left( \sum_{i=1}^{N} a_i^2 \right) / N a_0^2$$

but only the compact information of the resulting level is retained in its internal memory.

As previously shown, correlation is defined as a continuous time integral but it must be computed here from discrete time signals. In this case it is useful to compute it in the frequency domain by using the Discrete Fourier Transform (DFT) operator: frequency domain correlation can be efficiently computed by simply multiplying the DFT of the first signal by the conjugate of the DFT of the second signal. This gives an information about the frequency spectrum of correlating signals and allows to detect eventual disturbances. By anti-transforming this spectrum one can get the correlation in time domain. The main caution to be adopted is to apply windowing of the discrete time signal in order to reduce the spectral leakage due to the truncation of the considered time domain sequence. Here a Blackman-Harris window is used and transformation is done via Fast Fourier Transform (FFT) algorithm.

A software interface based on Microsoft™ VisualC# language has been developed and used for testing purposes (Fig. 7). It offers the following features:

- noise loggers programming for noise levels recording, when acquisition times and durations are transferred from the local PC or remotely;
- downloading of the pre-processed data regarding noise levels acquisition (leak values);
- synchronization of the noise loggers and programming of the acquisition time and extension;
- estimation of the sound speed in the pipelines starting from their physical characteristics;
- downloading of the noise signals recorded by the sensors.

Cross correlations are offline performed through another graphical user interface (Fig. 9.b) that uses the built-in functions provided by MatLab™.

**Preliminary testing**

Several preliminary laboratory trials have been carried out in order to:

1. calibrate the noise levels to compute the probability of leakages;
2. localize leakages along a steel pipe (usually used for irrigation inside a laboratory greenhouse): the leakage was simulated by opening an intermediate tip.

The step no. 1 in the list was performed collecting vibration data from a mock-up installation and “leak value” levels from a commercial system working in parallel with the prototype under development. The setup was obtained like in Fig. 8: a steel pipe was supported by two resilient bases and caused to vibrate through a small fan; vibration levels at the points depicted in Fig. 8 were measured first using a commercial noise logger (which records leak values) and then using the prototypical noise logger whose accelerometers measured vibration’s sound intensity. Then a best fitting algorithm between the LV estimated by the commercial systems and the sound intensity and spread measured by the system under development were applied according to eq. (1), which gave back the following coefficients estimations: \(c_1=-12.58\); \(c_2=4.32\); \(c_3=-0.12\). Correlation gave back an R-squared equals to 0.9743, which is acceptable.

The trail in step no. 2 was performed on an above-ground pipe, which is used by the laboratory personnel for irrigation and water distribution to the various users of the laboratory (Fig. 9.a). First noise levels estimated by the noise loggers when water is not flowing were verified to be very low (under 10 dB restituting an LV almost null). Then a leakage situation was simulated through opening one of the derivations from the pipe located approximately in the middle and noise levels were noticed to rise. In addition, the software in Fig. 7 was run to insert inputs regarding pipeline features (Fig. 9.b), synchronize the loggers, record 16 s long signals at each end of the pipe and estimate the leakage position, like in Fig. 9.c.

The error between the real position of the fake leakage and the estimated one resulted to be lower than 1 m, which is acceptable by those in charge of making a survey, excavating and replacing the portion of broken pipe.

**On-field trials**

Finally, given the high criticality of the communication system, an on-field test was performed to assess the capabilities of the system to send signal from underground. The main purpose was estimating the maximum distance allowed between buried noise loggers and repeaters, and then verify that noise levels are correctly transferred (which means the packets have not been corrupted by too low communication power). The site was offered by the “Azienda Multiservizi” of Ancona, and it was performed at a residential district in the small town of Agugliano (AN). Two noise loggers were installed in two inspections pits like in Fig. 10.a, separated by a distance of 106 m. Then each repeater was moved away from each noise logger until the maximum communication distance was reached, which resulted to be equal to 60m (Fig. 10.b). Finally the above described software was used to acquire and analyze noise levels at that time, which gave back the results in Fig. 10.c, meaning that:
- when the distance between noise loggers (0.8 m underground in concrete pits) and repeaters is equal to 60m noise levels are not corrupted and the communication works well;
- during the on-site tests, performed at about 4 pm, there was no leakage and relatively water low volume flow, which acceptable, because the residential area was built few years ago (hence the pipelines are quite new) and no people were at home, being a working day.

Fig.10. Installation of the noise loggers on a real pipeline (a), maximum distance between loggers and repeaters (b) and noise levels diagrams processed by the two loggers (c)

CONCLUSIONS
Integrated water resources management at the district level asks for the availability of a widespread communication networks and intelligent algorithms to offer several services. In this paper we have done a first step towards water supply systems leak automated detection, which provided the following good results: the implemented algorithm for leak probability assessment and leakage positioning worked well during laboratory trials; the communication system performed well even when installed on a real site. Future research step will be devoted to the simulation of a permanent installation of the system, in order to check its capability to locate leakages in real pipelines and also to communicate remotely and to transfer long packets (noise signals several seconds long for correlation) from noise loggers to repeaters.

ACKNOWLEDGMENTS
The authors are very grateful to the company “Azienda Multiservizi” of Ancona, which provided the water supply systems where on-site testing was carried out. Special thanks to the company Smart Space Solutions S.r.L. (www.smartspace.it) for manufacturing the customized noise loggers developed in this paper.

REFERENCES
Gerontechnology acceptance by older Hong Kong people

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Purpose Technology develops at tremendous speed and its impact on our daily life is immense. However, studies have found that older adults are less likely to use technologies than younger people. The purpose of this study was to investigate the gerontechnology acceptance by the older population in Hong Kong. Acceptance was examined in terms of attitude and usage behaviour. Method Using extended Technology Acceptance Model (TAM) which incorporates health abilities and quality of life constructs, we investigated the contributing factors to the use of general gerontechnology by older adults in Hong Kong. Usage behaviour was measured in terms of degree and domains of use. Data in this study were collected at six centres for the elderly in Hong Kong through a questionnaire survey administrated by a structural interview approach. Items in the questionnaire were developed based on the previous research. Results & Discussion A total of 104 seniors, aged between 60 and 91, participated in the study. The Statistical Package for the Social Sciences software was used to analyze the data. The results show that basic technologies such as television and mobile phones had a high level of adoption by the respondents. However, the usage rate of high technology products, like health monitoring system and telemedicine was very low. Generally, older adults had a positive attitude towards gerontechnology, but they thought technological products and services were difficult to use and expensive. Multiple regression results indicated that older adults who were younger, females, better educated, and had higher incomes were more likely to use gerontechnology. Usefulness, ease of use, attitude, and behavioural intention were found to have no direct effects on actual usage. Mobility was negatively related to usage, whereas health satisfaction and participation in social activities increased usage. Implications and suggestions of this study are discussed.

Keywords: Communication & governance, technology acceptance and usage, Hong Kong

INTRODUCTION Technology develops at a tremendous rate today and its impact on daily life is immense. Gerontechnology aims to apply technology to deal with problems and difficulties arising from ageing so as to give older people the chance to lead lives that are healthier, more independent and more socially engaged on a continuing basis. The emphasis in gerontechnology is on creating innovative technologies to improve functional capabilities and to compensate for declining physical abilities for the ageing population. Studies have found that although many older people have positive attitudes towards technology, the usage rates for technologies like mobile phones and computers by the seniors are still low. A lot of research has been done in America and Europe on various aspects of gerontechnology, some of it looking, for example, into the attitudes of older people towards different kinds of technologies like information and communication technology, assistive technology, health technology, and so forth. However, very few similar studies have been conducted in China, even though it has been shown that people from different backgrounds are likely to have different attitudes towards acceptance of technology. Several cross-culture studies have demonstrated that people from different cultures have different perceptions and uses of technologies. It seems very likely then that, due to the many variations in geography, society, and politics between Asia, Europe and America, the usage and perceptions of technology by older adults will be different across the corresponding cultures. A study by Sun and Zhang has confirmed that cultural background could be a constraint affecting the behavioral intention of an individual with regard to technology usage. Currently, most studies on usage of technology by older people have been carried out in Europe and America, but as yet Asian countries, with a large percentage of the older population of the world, have not been widely explored. It is not known to what extent the findings for populations in developed countries can be generalized to the older populations in developing countries. As a result, research aimed at investigating the usage and acceptance of technology by older people in China will be valuable since China accounts for a large proportion of the older population of the world. Technological products and services can be categorized in such terms as, operating difficulties, functionalities and intended uses, etc. Previous research on technology and the older population has generally focused on specific kinds of technology, especially...
the communication and assistive technologies in the home. Other categories, such as personal mobility and transportation, and education and recreation have been largely neglected.

In order to fill in some of the gaps in the research, this study is directed at examining the acceptance of gerontechnology products and services by older people in Hong Kong. It aimed to find out: (1) the usage rates of different kinds of technological products and services among older people in Hong Kong; and, (2) the factors that influence the acceptance of gerontechnology by older people in Hong Kong. It is hope that this study on the ageing population in Hong Kong will act as a stimulus and basis for further comparative studies in China and other Asia countries.

**Research Framework**

**TAM**

Technology acceptance has been described as “the approval, favorable reception and ongoing use of newly introduced devices and systems”. When investigating the acceptance and usage of a technological product or service, the Technology Acceptance Model (TAM) developed by Davis is the most widely used. The TAM was originally designed to forecast the acceptance of information technology. It states that usage behavior is predicted by intention to use (BI) which is dependent on perceived usefulness (PU) and attitude towards using (AT), and attitude is in turn determined by perceived usefulness (PU) and perceived ease of use (PEOU). PU was defined as “the degree to which a person believes that using a particular system would enhance his or her job performance” and PEOU was defined as “the degree to which a person believes that using a particular system would be free of effort.”

The TAM has been widely used to investigate user adoption of the Internet, mobile phones, assistive or health technologies, and so on. Several meta-analysis studies have proved TAM to be the most-used, powerful and robust predictive model for technology usage. For example, King and He performed over 12,000 investigations within 88 studies of the TAM and concluded that the measurement variables in TAM were reliable and could be utilized in different contexts. Although the TAM exists as a reliable acceptance theory, it suffers from inadequate explanatory power since different contexts and factors will affect the validity of the constructs in TAM. Therefore, it has been suggested that more factors should be incorporated into the TAM when measuring user acceptance of technologies. A number of studies have shown the effectiveness of incorporating moderating factors to increase the explanatory power of TAM. Important among those factors are social norms, trust, compatibility, and self-efficacy.

However, current TAM studies have not considered age-specific factors when examining acceptance of technology by older populations. It is known that with ageing comes related deterioration of physiological and psychological abilities, which will inevitably affect ability to use technology products and services. For instance, decreases in vision and hearing are very likely to hinder seniors in using equipment and technologies that rely on visual and auditory information transfer. Older adults often experience deterioration of muscular dexterity and control, which may cause difficulties when operating small buttons and more complex controls. Older user also requires a longer time to process information. As age increases, memory function decreases, in particularly short-term memory, and this can affect daily living a great deal. Older adults may find a new technology hard to learn because their age related memory decline will have widespread effects on their ability to acquire and store new knowledge and skills. However, previous studies have not given much consideration to age-related health and associated abilities when examining acceptance of technology by the ageing population. This study intends to make progress in overcoming this omission by including age-related factors, in terms of quality of life and health abilities, in TAM.

To cope well with ageing it is important to: maintain physical, cognitive and social activities; live independently in a manner of his/her own choosing; and enjoy a high level of quality of life. Social interaction, life satisfaction and well-being are significantly related to successful ageing. The World Health Organization (WHO) defines quality of life as “individuals’ perceptions of their position in life in the background of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns”. Quality of life includes domains of physical health, psychological well-being, social and interpersonal relationships, environmental conditions and spiritual commitment. In this study, quality of life is comprised of living environment, satisfaction with financial and life situation, while health abilities are taken to mean those things that are greatly affected by general health, like satisfaction with health condition, and ability to move, learn and participate in social activities. It is envisaged that quality of life and health abilities will influence actual usage of gerontechnology by older people in Hong Kong.

**Hypothesis development**

Based on the theoretical framework, the following hypotheses are proposed:

H1.1 - H1.3: Perceived usefulness will be positively associated with attitude, behavioral intention and usage.
H2.1 and H2.2: Perceived ease of use will be positively associated with attitude and usage.
H3.1 and H3.2: Attitude toward using will be positively associated with behavioral intention and usage.
H4: Behavioral intention will positively predict usage.
H5.1 - H5.3: The quality of life constructs, i.e., living environment, financial satisfaction and life satisfaction will have positive influences on usage.
H6.1 - H6.4: Health abilities are; health satisfaction, movement ability, learning ability and participation in social activities; and will have a positive impact on usage.

METHODOLOGY
Participants
The population in this study was Hong Kong Chinese people aged 60 and above. The samples were generated using convenience sampling from six Neighborhood Elderly Centres and District Elderly Community Centres in Hong Kong. 104 respondents comprising of 26 males and 78 females participated in the study, with ages ranging from 60 to 91. The majority of the respondents were female (75.0 %), in the age bracket 70 to 79 (68.3 %), living with children and/or with spouse (41.3 %), retired (98.1 %), with no education or primary education or below (61.6 %), living in private housing (54.8 %) and with a monthly income between HKD 4000 to 6999 (34.6 %). Table 1 summarizes the demographic characteristics of the respondents.

Table 1. Demographic characteristics of the respondents (n = 104)

<table>
<thead>
<tr>
<th>Demographic Characteristics</th>
<th>Frequency (n)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>26</td>
<td>25.0</td>
</tr>
<tr>
<td>Female</td>
<td>78</td>
<td>75.0</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60-69 years old</td>
<td>11</td>
<td>10.6</td>
</tr>
<tr>
<td>70-79 years old</td>
<td>71</td>
<td>68.3</td>
</tr>
<tr>
<td>80 years old or above</td>
<td>22</td>
<td>21.2</td>
</tr>
<tr>
<td>Status of household members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living alone</td>
<td>40</td>
<td>38.5</td>
</tr>
<tr>
<td>With children only/With children and spouse</td>
<td>43</td>
<td>41.3</td>
</tr>
<tr>
<td>With spouse only</td>
<td>21</td>
<td>20.2</td>
</tr>
<tr>
<td>Employment status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full time</td>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>Retired</td>
<td>102</td>
<td>98.1</td>
</tr>
<tr>
<td>Level of education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uneducated</td>
<td>32</td>
<td>30.8</td>
</tr>
<tr>
<td>Primary or below</td>
<td>32</td>
<td>30.8</td>
</tr>
<tr>
<td>Form 1 to 3 (Secondary education)</td>
<td>23</td>
<td>22.1</td>
</tr>
<tr>
<td>Form 4 to 5 (Senior Secondary)</td>
<td>8</td>
<td>7.7</td>
</tr>
<tr>
<td>Form 6 to 7 (Matriculation course)</td>
<td>7</td>
<td>6.7</td>
</tr>
<tr>
<td>Associate or Diploma</td>
<td>2</td>
<td>1.9</td>
</tr>
<tr>
<td>Occupation before retirement</td>
<td>14</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Procedure
A survey questionnaire was administrated to the participants though a structured interview which was done in May and June 2010 in six centres for the seniors in Hong Kong. Since the data collection procedure was done by trained interviewers, all the questionnaires were collected without missing answers.

Measurement
Technology acceptance was examined in terms of attitude and usage behaviour. The measurements were developed based on previous TAM research and comprised of four parts: 1) use of technology products and services; 2) perceptions and attitude about general technology products and services; 3) quality of life and health abilities; and 4) demographic information.

Use of gerontechnology was measured in terms of degree and domains of use. Technology products and services were categorized into five domains as suggested by Fozard16, which include housing and daily living; communication and governance; personal mobility and transportation; health and self esteem; and work, recreation and self-fulfillment. A total of 22 technology products and services were listed and the degree of use was measured by asking the respondents whether they: 1) have been using the technology product/service; 2) had heard of the technology product/service but not used in the past six months; 3) had not heard of the technology/service. The Cronbach’s alpha value for this scale was 0.704. Perception and acceptance of gerontechnology was based on the TAM, which includes the constructs of
perceived usefulness, perceived ease of use, behavioral intention and attitude. Perceived usefulness (PU) was defined as the users feeling of improved performance when they use the technology. Perceived ease of use was defined as the strength of one’s belief that interacting with the technology product/service would be free of effort. Behavioral intention was measured using a three-item scale. All constructs were measured using a 10-point Likert scale indicating respondents’ agreement with the description given by the related sentence. The Cronbach’s alpha value for this scale was 0.955.

The measurement of the quality of life consisted of self-rated satisfaction with their living environment, financial condition, and satisfaction with life overall. Health abilities were measured by overall health condition, movement satisfaction, learning ability and the frequency of participating in different social activities. The respondents rated their levels of satisfaction on a 10-point scale. The reliabilities of the scales of quality of life and health abilities were 0.887 and 0.738 respectively.

Pilot study
Before the data collection process, a pilot study was conducted in order to ensure the questions were suitable in terms of difficulty, comprehension, length and significance. The questionnaire was administrated to a sample of five respondents selected by convenience sampling in an elderly centre. The test setting mirrored the planned survey test proper setting as closely as possible. The survey instrument was revised based on the results of the pilot study in terms of modifying the wordings, adding/deleting questions, etc.

Data analysis
The Statistical Package for the Social Sciences (SPSS) was used to describe and analyze data for this study. A confidence level of 95% was chosen as the criterion for testing the hypotheses.

RESULTS
Use of gerontechnology
In this study, the respondents’ use of different types of technology was investigated. The result is shown in table 2. When gerontechnology products or services were categorized into survival, basic, and high technology; there were clearly different adoption rates between the three types of technology. The adoption rates decreased gradually from survival to basic technology and drastically for high technology. For products/services in the survival level category, all of the respondents or had been using television (100%) and majority of them were or had been using the kitchen stove (96.2%), reading glasses (75%), exercise equipments (74%), and walking stick (60.6%). The handle trolley shopping bag had been adopted at a relatively lower rate (21.2%), which might be because the older people did not need purchasing a lot of domestic goods and products and they could carry them without the help of the trolley bag.

Table 2. Responses about usage of technology products/services (n=104)

<table>
<thead>
<tr>
<th>Products/services</th>
<th>Not heard of (%)</th>
<th>Heard of (%)</th>
<th>Used or using (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survival technology level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Television</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Kitchen stove</td>
<td>0.0</td>
<td>3.8</td>
<td>96.2</td>
</tr>
<tr>
<td>Reading glasses</td>
<td>0.0</td>
<td>25.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Exercise equipment</td>
<td>0.0</td>
<td>26.0</td>
<td>74.0</td>
</tr>
<tr>
<td>Walking stick</td>
<td>0.0</td>
<td>39.4</td>
<td>60.6</td>
</tr>
<tr>
<td>Handle trolley shopping bag</td>
<td>0.0</td>
<td>78.8</td>
<td>21.2</td>
</tr>
<tr>
<td><strong>Basic technology level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATM</td>
<td>4.8</td>
<td>78.8</td>
<td>16.3</td>
</tr>
<tr>
<td>Combination lock</td>
<td>2.9</td>
<td>41.3</td>
<td>55.8</td>
</tr>
<tr>
<td>Digital camera</td>
<td>1.0</td>
<td>76.9</td>
<td>22.1</td>
</tr>
<tr>
<td>Massage</td>
<td>0.0</td>
<td>78.8</td>
<td>21.2</td>
</tr>
<tr>
<td><strong>High technology level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home Automation System</td>
<td>62.5</td>
<td>37.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Home health monitoring system</td>
<td>71.2</td>
<td>28.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Touch screen mobile phone</td>
<td>59.6</td>
<td>40.4</td>
<td>0.0</td>
</tr>
<tr>
<td>GPS</td>
<td>61.5</td>
<td>38.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Telemedicine</td>
<td>75.0</td>
<td>25.0</td>
<td>0.0</td>
</tr>
<tr>
<td>PDA</td>
<td>50.0</td>
<td>50.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Network communication</td>
<td>26.9</td>
<td>71.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Internet/E-Learning/Computer games</td>
<td>12.5</td>
<td>50.0</td>
<td>37.5</td>
</tr>
</tbody>
</table>

For the products/services in the basic technology category, some of the products/services were or had been adopted by the respondents, such as public transport (84.6%), mobile phone (76.9%), DVD/VCD/CD player (55.8%), combination lock (55.8%), and security alarm (41.3%). While the digital camera (22.1%), massage chair/equipment (21.2%) and automatic teller machine (ATM) (16.3%) received much lower adoption rates but almost all of the respondents had heard of them. It may be seen that mobile phones had been widely adopted by the seniors for communicating with their children, spouse and friends. Many of the respondents reported that their mobile phones were bought by their children because of its convenience as a means of keeping in touch.

When looking at the result for high technology products and services, it is apparent that the respondents did not use those products/services, with the excep-
tion of internet/e-Learning/computer games which were adopted by approximately one-third of the respondents (37.5%). The usage rates for other high technology products and services like home automation system, personal digital assistant (PDA), and telemedicine were zero. Moreover, more than 60% of the respondents had not even heard of home automation system, home health monitoring system, GPS and telemedicine. In general, the respondents had accepted and used survival technologies and adopted the basic technologies to some degree. However, they were mostly unaware of or not users of high technology products/services and advances in these technologies, some of which might be of considerable benefit to them. Many of them did not have the knowledge to recognize the potential usefulness of these products/services to improve the quality of their lives.

Predictors of acceptance of gerontechnology
A composite score was obtained by summing up all the responses on the scale of use of technology. Hierarchical regression was used to examine the factors which contribute to the use of gerontechnology by older adults in Hong Kong. The dependent variable was actual use of gerontechnology. For the first model used here, the independent demographic variables which included age, gender, education, and monthly income were entered into what is called Model 1 here (Table 3). Then, the variables from the TAM constructs, perceived usefulness, perceived ease of use, attitude toward using, and behavioral intention were added for Model 2. Finally, the constructs of quality of life and health abilities were added for Model 3, which was the most detailed model used here. The results are presented in Table 3.

The results showed that usage of gerontechnology by older adults in Hong Kong could be predicted by age, gender, education, monthly income, health satisfaction, movement ability, and participation of social activities. These factors jointly explained 80.7% of the variance in actual use of gerontechnology. Age was negatively related to use of gerontechnology, indicating older seniors used fewer technologies than younger seniors. Females were more likely to use technology than males. Education level and income were positively related to usage, which indicated that people with higher levels of education and with more monthly income would use more technologies. Moreover, the TAM constructs, that were perceived usefulness, perceived ease of use, attitude towards using, and behavioral intention, were found to have no direct influences on usage. Therefore, H1.3, H2.2, H3.2 and H4 were not supported. In the TAM, perceived usefulness and perceived ease of use were supposed to jointly determine attitude towards using which then predicts usage intention. For this reason, the hierarchical regressions with the same independent variables were employed to examine the predictors of behavioral intention and attitude. It was found that perceived usefulness and ease of use positively predicted attitude towards using, which confirmed H1.1 and H2.1. Also, usefulness and attitude towards using had positively influences on the behavioral intention to use gerontechnology, and thus H1.2 and H3.1 were supported.

Quality of life factors, i.e. living environment, financial satisfaction and life satisfaction did not directly affect usage. Therefore, H5.1, H5.2 and H5.3 were not supported. Health satisfaction and social activities participation were found to positively predict usage, which confirmed H6.1 and H6.4. Older adults who had better health and frequently participated in social activities were more likely to use technologies. Contrary to the expectation of H6.2, movement ability decreased usage, which indicated that people with poor movement ability used more technologies. With regards to learning ability, it did not have direct relationship with usage and thus H6.3 was not supported.

Table 3. Hierarchical regression on usage of gerontechnology

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Model1</th>
<th>Model2</th>
<th>Model3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.404***</td>
<td>-0.338***</td>
<td>-0.399***</td>
</tr>
<tr>
<td>Gender</td>
<td>0.371***</td>
<td>0.322***</td>
<td>0.291***</td>
</tr>
<tr>
<td>Education</td>
<td>0.502***</td>
<td>0.406***</td>
<td>0.302***</td>
</tr>
<tr>
<td>Monthly income</td>
<td>0.322***</td>
<td>0.228***</td>
<td>0.189***</td>
</tr>
<tr>
<td>Perceived usefulness</td>
<td>0.050</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>Perceived ease of use</td>
<td></td>
<td>-0.029</td>
<td>-0.120</td>
</tr>
<tr>
<td>Attitude toward using</td>
<td>0.204</td>
<td>0.199</td>
<td></td>
</tr>
<tr>
<td>Behavioral intention</td>
<td>0.047</td>
<td>-0.123</td>
<td></td>
</tr>
<tr>
<td>Living environments</td>
<td></td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>Financial satisfaction</td>
<td></td>
<td>0.109</td>
<td></td>
</tr>
<tr>
<td>Life satisfaction</td>
<td></td>
<td>-0.054</td>
<td></td>
</tr>
<tr>
<td>Learning ability</td>
<td></td>
<td>-0.074</td>
<td></td>
</tr>
<tr>
<td>Health satisfaction</td>
<td></td>
<td>0.426***</td>
<td></td>
</tr>
<tr>
<td>Movement ability</td>
<td></td>
<td>-0.148*</td>
<td></td>
</tr>
<tr>
<td>Social activities</td>
<td></td>
<td>0.291***</td>
<td></td>
</tr>
<tr>
<td>F-value</td>
<td>41.045***</td>
<td>23.987***</td>
<td>24.600***</td>
</tr>
<tr>
<td>R²</td>
<td>0.624</td>
<td>0.669</td>
<td>0.807</td>
</tr>
</tbody>
</table>

Verbal responses
Since the structured interview technique was adopted, the opinions and feelings expressed by the respondents during the interview were collected. Table 4 shows the opinions and reasons given by the respondents for not adopting a particular kind of technology product/service. These opinions provided an
It was found that survival technologies have particu-
larly high adoption rates, which means the survival 
level technologies are already embraced by many 
elders in Hong Kong. Moreover, basic level tech-
nologies were quite widely known and had a moder-
ate adoption rate. The high usage rates among sur-
vival and basic technologies could be due to the fact 
that they had been in use for a relatively long time in 
society. When a new technology product/service is 
introduced into a market, it is often identified as high-
tech (e.g. mobile phone in 80s) and is expensive. 
However, as time goes by, the technology prod-
uct/service gradually becomes universal, it is no 
longer high-tech, the price comes down, and the 
general public have greater access to the technology. 
In this research, survival technologies had a particu-
lar high adoption rate which may be because many 
of the survival technologies are related to housing 
and daily living (e.g. stove, reading glasses), and 
they are common electrical appliance. The prices of 
the survival technologies are reasonable and afford-
able for older users.

For basic technologies, the adoption rates varied 
among different products/services. For example, 
Automatic Teller Machine (ATM) had quite a low 
adoption rate. Many of the respondents reported 
that they had used ATMs, but they had bad experiences 
with them. Respondents said that they found it hard 
for the words or comprehend the meaning of the 
messages shown on the monitor due to visual prob-
lems or illiteracy. A majority of the respondents ex-
pressed concern about safety and security problems. 
They claimed that they have had a card confiscated 
by an ATM and this caused them fear of using an 
ATM again. This concern about safety and security 
issues has also been reported in a previous study20. 
The findings showed that a majority of the respond-
ents had used or were using mobile phones. This 
widespread use may be attributed to the relatively 
low price of mobile phones nowadays due to the 
rapid advances and spread of mobile technology. 
Previous research has shown that for seniors, ease 
of use and price are the factors that concern them 
most when purchasing a mobile phone2,40. Also, local 
marketing has exploited the seniors’ market by intro-
ducing mobile phones with simple, useful functions 
like a safety alarm, and prices are reasonable which 
suits the budget of seniors. Local telecommunication 
companies also have introduced special lower price 
plans for the aged.

For high technologies the adoption rate was much 
lower than for survival and basic technologies. High 
technologies are by definition involve innovation and 
the users often have to exert considerable effort to 
learn new skills to use new products/services. As 
suggested by Bouma et al.14, seniors often have 
difficulty in adopting new technologies and learning 
new skills because they become accustomed to a 
routine way of life over a long time and they may not 
perceive these high technologies to be useful. Also, 
when they were young the rate of change was much 
slower and people did not expect to adopt some new 
technology every few years. Furthermore, the aged 
experience deterioration of perceptual and cognitive 
abilities which can greatly affect their performance 
and interaction with equipment. The ability to under-
stand things and to learn decrease with age, and 
information processing time is longer, all of which 
creates extra burdens and barriers to taking up new 
technologies.

**Perceptions and acceptance towards technology**

The perception and acceptance of older people with 
regard to gerontechnology was measured using the 
Technology Acceptance Model (TAM). It was found 

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**Table 4. Reasons expressed by respondents on not adopting technology products/services**

<table>
<thead>
<tr>
<th>Technology products/services</th>
<th>Reasons for not adopting them</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer/ Internet</td>
<td>Too old to learn/ cannot memorize the operating procedures</td>
</tr>
<tr>
<td></td>
<td>Too difficult to operate</td>
</tr>
<tr>
<td></td>
<td>Illiterate/ do not know English</td>
</tr>
<tr>
<td></td>
<td>Too expensive</td>
</tr>
<tr>
<td>Mobile phone</td>
<td>Too troublesome to pay the phone bills every month</td>
</tr>
<tr>
<td>Message chair</td>
<td>Too expensive</td>
</tr>
<tr>
<td>Automatic teller machine (ATM)</td>
<td>Could not see the words on the monitor clearly</td>
</tr>
<tr>
<td></td>
<td>Could not remember the password and fear for the card being confiscated by ATM</td>
</tr>
<tr>
<td>Security alarm</td>
<td>The monthly fee was too expensive</td>
</tr>
<tr>
<td></td>
<td>Not necessary since living with spouse/children</td>
</tr>
<tr>
<td>Public transport</td>
<td>Health condition/ mobility was too poor for traveling</td>
</tr>
<tr>
<td>Touch screen mobile phone</td>
<td>Too difficult to control</td>
</tr>
<tr>
<td></td>
<td>Too expensive</td>
</tr>
</tbody>
</table>

**DISCUSSION**

**Use of gerontechnology**

For this study the Technology Acceptance Model (TAM) was expanded to incorporate health abilities and quality of life constructs. Using expanded models, the factors which contribute to the use of general gerontechnology by older adults in Hong Kong were investigated. Data in this study were collected in six elderly centres in Hong Kong through a questionnaire survey administrated though a structured interview approach. One hundred and four respondents aged 60 years and older participated in this study.

It was found that survival technologies have particu-
larly high adoption rates, which means the survival 
level technologies are already embraced by many 
seniors in Hong Kong. Moreover, basic level tech-
nologies were quite widely known and had a moder-
ate adoption rate. The high usage rates among sur-
vival and basic technologies could be due to the fact 
that they had been in use for a relatively long time in 
society. When a new technology product/service is 
introduced into a market, it is often identified as high-
tech (e.g. mobile phone in 80s) and is expensive. 
However, as time goes by, the technology prod-
uct/service gradually becomes universal, it is no 
longer high-tech, the price comes down, and the 
general public have greater access to the technology. 
In this research, survival technologies had a particu-
lar high adoption rate which may be because many
that age, gender, education level, and income directly influenced the use of gerontechnology. This result is consistent with previous studies showing that increasing age was associated with decreased use of gerontechnology\textsuperscript{18,41,42}. Education level and income positively related to use of technology. People with higher education and income had more chances to use gerontechnology. An interesting finding was that females were more likely to use gerontechnology than males.

Perceived usefulness, perceived ease of use, behavioral intention, attitude towards technology, and usage behavior for older people were investigated in this study. Results indicated that older adults in Hong Kong generally have a positive view towards technology. Although the respondents perceived technology as useful and had positive attitudes, they thought that technology products/services are difficult to operate.

In agreement the expectations from TAM, in this study, perceived usefulness and perceived ease of use were found to be predictors of attitude towards using gerontechnology and this had a positive effect on behavioral intention to use gerontechnology. McCreadie and Tinker\textsuperscript{22} suggested that the “felt need”, i.e., the individual feeling that the technology is useful, is central to technology adoption. Consensus among researchers exists that older people would accept and use of new technologies if they believed and realized that those technologies might be used to improve their lives and satisfy their needs\textsuperscript{2,43}. Perceived ease of use is also an indicator of attitude. Previous studies have indicated that older people are more likely to accept technologies that are easy to understand and have a simple interface design\textsuperscript{5,18}. However, outside the expectations here were the results that perceived usefulness, perceived ease of use and attitude towards use were not directly related to actual use. The direct relationship expected between behavioral intention and actual usage was also not found, and this result differs from the findings of previous research\textsuperscript{29,44}. Turner\textsuperscript{44} performed a systematic literature review of 79 relevant empirical studies in 73 articles using vote-counting meta-analysis, and found that perceived usefulness and perceived ease of use were not so likely to predict actual usage, and this is consistent with our finding. The non-significant relationship found here between behavioral intention and actual usage might be due to some ambiguity in the questions, in that, the measures of intention of use and actual usage did not specify the type of technology. The self-reported usage may also be another reason for the inconsistency. Self-reported usage can be subject to method bias, and this will distort the result which might, therefore, not represent actual usage behavior\textsuperscript{45}.

This study extended previous work by considering the effects of quality of life and health abilities for the prediction of acceptance of technology by older adults. The results indicated that when demographic variables and TAM construct were controlled, quality of life constructs, i.e., living environment, financial satisfaction and life satisfaction were not direct determinants of usage. Health satisfaction was positively associated with usage. It is known that ageing brings with it changes in perception, cognition, movement, and psychosocial functioning\textsuperscript{33,34}, and these changes may influence an older person’s needs and his or her capabilities to use a technology or technical devices. People with poor health might find that interaction with technology is not easy for them. Age related visual and hearing impairments may influence the ease with which these technologies are used. Most electronic appliances like DVD players are equipped with small digital displays, and older people with poor visual acuity will have difficulty in reading message from such appliances. Previous study has found that older adults with physical difficulties in vision, hearing and motion used fewer technologies than people with good health\textsuperscript{46,47}. It has also been shown that people with higher levels of crystallized and fluid intelligence used a greater variety of different types of technology\textsuperscript{48}. Furthermore, the decline in perception and cognition abilities in older people may decrease their performance when trying to use a particular technology. For example, in a web usability study, Chadwiek-Dias\textsuperscript{49} found that older users (55 years or older) took a longer time to finish tasks, had lower task success rates, and fewer mouse clicks per minute than younger adults. This is consistent with our finding that people with better health were more likely to use technology.

The results here show that participation in social activities may increase the use of technology. Older adults who take part in social activities are likely to receive more new information on technology products/services and share their usage experience with others. Beside, when they experience difficulty in using a technology, their peers may be able to provide help for them and this can make their attitude towards acceptance of technology generally more positive. An active lifestyle and participation of social activities may increase willingness to learn about new things and perhaps be more accepting of new advances in technology\textsuperscript{50}. Social factors also contribute to the development of the necessary motivation to learn about and to use technology\textsuperscript{51}. Contrary to expectation, movement ability deceased actual usage. A possible explanation might be that, included in the measurements here were mobility technologies, such as walking stick, trolley bags and mobile phones, which were mainly used to compensate for lack of mobility. Also, technologies like tele-
phones, computers and online-shopping can benefit people with poor movement ability by reducing the need or frequency for trips out. Therefore, people with less mobility might benefit more by use of those technologies.

Other factors
In this study, some additional factors affecting the acceptance of technology by older users were elicited through the interviews. Cost was found to be related to use of technology. As suggested by Mallenius, the price of a product/service is an important consideration for seniors. The cost of a product includes the first costs (i.e. purchase cost) and the long term cost such as maintenance and repair expenditure. The cost of purchasing new technologies and the monthly service fee of maintaining the services (e.g. security alarm) could be barriers to some older users.

The respondents said that they often feel anxiety about using technology and are afraid of making mistakes they could not correct. Older adults tend to worry about handling new technologies and avoid them because of the fear of making mistakes. For instance, respondents reported that they were frightened that they would forget their password when using an ATM. They were also afraid that they might misuse and therefore damage domestic appliances.

Contributions and Limitations
This study examined the factors affecting acceptance and use gerontechnology by the ageing population in Hong Kong. It aimed to increase understanding about the design and effectiveness of technology to improve the quality of life for seniors. The present study has some theoretical and practical contributions and intends to raise the awareness of technology impacts on the ageing population in Hong Kong.

It was found that health satisfaction positively predicts actual usage of gerontechnology. This result suggests that designers should determine whether older users are able to withstand the physical and psychological demands made by the product/service they will use. For example, with age comes a gradual and inevitable decline in physiological functioning particularly in sensory systems which include vision, hearing, and thermal comfort. Other problems that older people often encounter are difficulty in movement and decreased physical strength and endurance. Gerontechnology products have to be usable by the targeted users to serve its stated purposes in the intended environment. The strengths and limitations of the targeted users should be accommodated and the users should feel little or no fatigue or discomfort when they use gerontechnology.

The respondents here found technology products/services difficult to use. This may be because product designers do not consider the needs and characteristics of the ageing population in product design. The needs of older consumers are rarely considered and basic human factors are often overlooked since product developers tend to create products with the best attributes and functionalities of the product in mind, not the needs of the user. If developers put more emphasis on basic attributes when designing a product/service, it may give them a good opportunity to open their market for the aged who are rapidly increasing as a proportion of the population in many countries. This could be done by a user based assessment approach in the early stages of design.

The cost of the gerontechnology products and services was a major concern for older users. Moreover, the time required to obtain, set up and learn the usage skills for a product/service, are also costs for the user. These costs associated with a product have to be justified by its performance and benefits. This is vital because many of older people do not have strong financial support. Governments and developers may help here by providing some preferential arrangements, such as subsidizing technology usage activities, or establishing more facilities in communities and public locations, in order to encourage older people to make greater use of gerontechnology.

In this study, there were several limitations. Firstly, the survey relied on a convenience sample. Therefore, any generalization of the results should be done with caution. Further study may use random sampling with a larger sample size. Secondly, this research investigated a generic point of view on technology acceptance. It did not focus on the acceptance of a particular technology product/service. Further studies could employ a more specific approach. Thirdly, self-reported usage was employed and further study may consider more objective measures.

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5. McCloskey, D.W., "The importance of ease of use, usefulness, and trust to online consumers: An ex-


Aging and Architecture
Design Aids by Integral ‘Age-Proof’ Housing Models

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2 Research Education Design, Consultancy, Eindhoven, The Netherlands
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Purpose: The aim was to offer integral design aids for ‘age-proof’ housing. The main goal is to enable architectural designers to develop housing concepts of a higher than usual quality for aging users. Easy-to-follow models as design aids were developed in the context of R&D. These models indicate what to avoid, where protection is needed, and how to improve design in order to support aging people in their home. Those models are the central theme of the paper.

Method: Systematic integral design (Integral Bio-Logical Architecture - IBA) and model building, particularly for architectural concepts that develop devises or means according to principles of repetition and worldwide application of method of holistic participation (MHP).

Results & Discussion: We focus on elementary conditions to underpin the residents staying healthy and reaching old age, based on a proper and vital built environment. We do not elaborate on possible installations of valuable mechatronics or robotics for resident welfare. We discuss some design aids where the above mentioned design development methods were successfully used. We chose to focus on the principal conditions that determine the quality of sound architecture in relation to health, sustainability, and aging of residents and users. Aging of architecture is an historical objective in terms of interior, room, building, and town. Aging within architecture deals with the residents as principal participants. We conclude our systematically devised research approach by deducing models that can be used as check instruments and integral design aids for ‘age-proof’ housing and that offer practical applications in the housing design process as well as being a useful topic for multidisciplinary discussion.

Keywords: ‘Age-Proof’ Housing Model, Architecture and Aging, Integral Design Aids

INTRODUCTION

Within the broad fields of work, leisure, care, robotics, and construction for aging we go to focus on construction of housing, proper for its occupants while aging. In other words, housing and daily living are the main themes of this contribution. Even this field of housing or architecture and aging is a quite wide one, in which we distinguish three characteristic relations:

1 – Aging of architecture itself is an area of interest and the competence of history, and certainly an important item in the light of durability and sustainability. Architecture’s age is old as human building culture and as such an essential part of our ‘Kulturlandschaft’. Architectural objects can be temporarily, durable, or sustainable. Thus the age of these objects is an important economic, ecological, and cultural factor as well.

2 – Aging with architecture means aging of those people, who – creatively – are dealing with architecture. Some statistics concerning the reached age of architects were made – now and then and in some countries. A whole overview still is missing. However, it seems there is quite a significant number of architects and designers, who reached a relatively high age. One of my own respected teachers – Clemens Holzmeister – was active as architect until his late nineties. Millions of visitors enjoyed the Festspielhaus and Felsenreitschule in Salzburg, designed by him. Further impressive examples are: the Dutch architect Hendrikus Theodorus Wijdeveld, who, around his 100th birthday published a book ‘Mijn eerste eeuw’ (My First Century); and Grete Schütte-Lihotzky, designer of the famous Frankfurter Küche, reached also more then 100 years of age.

3 – Aging within architecture might be the humanly most important relation between aging and architecture – certainly for the dwellers or occupants. Because of this reason, we go to present design aids for ‘age-proof’ housing in order to make housing and instrument and element of service, which supports us in the period of increasing aging.

The presented design aids, also useful as check or ranking tools, are models, which were built on the principles of Integral Bio-Logical Architecture – IBA, a theory, which is characterized by special attention for environment as well as health in a holistic approach. IBA - studies, - research projects, and - practical applications for proposed and realized buildings started in the second half of the 1960ties. The increasing call for more and better dwellings, particularly for aging people, who mostly would prefer staying in their own living environment to which they are accommodated and used, cannot be overlooked anymore. It is therefore an important task to build – ‘age-proof’ dwellings and to refurbish existing
dwellings to transform them into ‘age-proof’ ones, if they are not.

**STRUCTURE OF THE DESIGN AIDS**

Buildings are necessary for survival, certainly in the less paradise-like climate zones of the planet, but also the reason for the complex and many-sided Sick-Building-Syndrome. In extreme cases: a building can kill its inhabitants, not only indirectly as a consequence of natural catastrophes, like earthquakes, but also directly as a consequence of using toxic building materials, or the lack of ventilation. Designing buildings gives a high responsibility to architects, planners, and building engineers, but also to building components producers and suppliers, contractors, housing estates, and politicians.

In this contribution we focus on the rough and basic conditions within buildings, which can help the inhabitants to stay healthy, or to recover in case of proper refurbishment, and to become older, because of a vital built environment. We don’t deal with possible installations of valuable mechatronics or robotics for the welfare of occupants. We discuss the main conditions what determine the ‘material’ quality of a sound architecture in relation to health and aging of dwellers and users.

Inherent in all following models is a ‘strategy’ of
1 – avoiding a lack, or short coming of the in the models mentioned qualifications (see the next paragraph);
2 – protecting the inhabitants against circumstances, which could or will be uncomfortable for them, or even heart them, by fulfilling the desirable qualities;
3 – improving the qualifications, for example in existing dwellings in order to support, or increase wellbeing and health.

Experience in designing and realizing buildings and their interior lead to the insight and conclusion that there are eight quality factors of high importance, which determine the quality of the whole including quality of life of the dwellers.

1 – indoor climate in terms of temperature, humidity, air / ventilation, light, and sound;
2 – surface of floors, walls, ceilings, etc. in terms of color, texture, thermal accumulation and conduction;
3 – access, or at least outlook to an outdoor area with plants, animals, people;
4 – save, secure, and ergonomically proper design, layout, equipment, and furniture;
5 – all applied materials for construction and completion: allergic-free and toxic-free;
6 – electro-magnetic neutral field;
7 – practical functionality, a suitable translation of the needs in rooms, for equipment, and furnishing;
8 – harmonious proportions in terms of patterns and colors (except the value of a certain heritage in the interior counts higher).

**METHODS OF JUDGMENT**

For how to judge qualities and how to forecast, or predict qualities of a designed, proposed, or demanded project and even of an executed project, we don’t have clear answers (yet).

Because of this reason we distinguish different approaches of ranking, or evaluating qualities – particularly in architecture:

1 – There is the broadly used subjective judgment, which often has strong influence on decisions and choices concerning qualities. Dependent on the ‘authority’ of the decision-making persons, many clients and residents can be touched – positively, or – even often – also negatively. Subjective judgment might be the usual way for ‘private’ decisions.

2 – In order to get a more ‘democratic’ solution, there is the possibility of an inter-subjective judgment, based on the impressions or opinions of a larger – preferably representative – number of respondents. Such a ranking process can be done systematically, and can lead to guidelines, which actually continuously should be under control.

3 – Measurable and measured parameter – if they are available and applicable – have a peculiar heavy weight in arguing and decision-making concerning various constellations and configurations of buildings and their interiors in the broadest sense. However, not all of the quality factors are measurable, still some (inter/subjective) interpretation is needed for choices between various possibilities.

Having recognized the possibilities and limits of ranking and relativity of judgment, we have to ‘confess’ that there is always some wisdom in combination with empathy needed in order to optimize decisions for a proper built environment.

**Figure 1. Basic pattern of ‘Age-Proof’ Housing Models – AHM for various design aids (‘sub’ models) related to physical, psychological, and spiritual expectations and requests of aging occupants, to be used in the various factor-focused models**

The factors that influence the quality of the built environment on the scale of dwellings are systematized in categories, and visualized in models. Those mod-
els bring the relevant influences under attention of designers, decision-makers, and clients, and they are useful for consultation about desirable qualities. The different possibilities of ranking and judgment can be adopted and they mutually can adjoin opinions, wishes, or demands to each other. The Method Holistic Participation – MHP can be advised as a convenient and effective instrument for decision-making by a team5,6,7.

**DESIGN AIDS AS AGE-PROOF HOUSING MODELS**

The models give you an idea about some physical or physiological, psychological, and spiritual or mental aspects or demands of our eight chosen considerable factors. Short explanations describe the core of those design aids. The visibly separated three paragraphs in the models give to the user indications for spiritual (at the top), psychological (in the middle), and physical (at the bottom) qualities, which have to be realized in age-proof housing. The 8 ‘sub’ models function as a simplified dictionary for utilizing wellbeing of dwellers.

**Indoor Climate**

Indoor climate – items as temperature, humidity, air quality, ventilation, light, sound, etc. supposed to be comfortable and healthy.

**Surface**

Surfaces of floors, walls, ceilings, etc. in terms of color, texture, thermal accumulation and conduction should be convenient and healthy.

**Outlook**

Outlook or even better access to an outdoor area with plants, animals, people, preferably also children should be easily possible and save.

**Security**

Save, secure and ergonomically proper design, layout of rooms without thresholds, save equipment, and furniture have high priorities.

**Material**

All visible and invisible materials for construction and completion as well as maintenance and cleaning have to be allergic-free and toxic-free.

**Field**

An electro-magnetic neutral field is important and preferable, certainly for extra- or supersensitive people ⁶, and according studies of nibe – Nederlands instituut voor bouwbiologie en ecologie.
Ergonomics
Practical functionality - a suitable translation of the needs into spaces for equipment and furnishing without barriers, and accessible for wheelchair - belong evidently to the demands as well as constructive flexibility.

Harmony
Harmonious proportions in terms of patterns and colors should be realized except the value of a certain heritage in the interior counts higher – in any case there should be a pretty atmosphere.

CONCLUSION
Some parts of this treatise might be evident. However the aim of this contribution was to pay attention also to the obviously ‘natural’ conditions within a building, which can support wellbeing and health for all occupants, but certainly for the aging ones. But at the same time it was the intention to include – integrally – beside the physical also the psychological and spiritual, or mental factors, which can determine the quality of life significantly. In order to make the models easily usable they follow a certain simplification of the complex interrelations of the concerned factors. Considering principles might be a better approach than (too) sharp manipulations in reaching satisfaction of the occupants.

We do hope that the integral ‘Age-Proof’ Housing Model – AHM will help the concerned and committed persons – teachers and students included – in reaching a healthy and properly built and equipped environment.

The structure of the presented models can be easily used for developing a related computer program. Nevertheless, there always will remain most probably a certain task for wise decision-making after all calculations.

References
A Bayesian Model for real-time safety management in construction sites

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Purpose This article reports on an ongoing research project, which is aimed at implementing advanced probabilistic models for real-time identification of hazardous events at construction sites. The model has intelligent capabilities for near real-time automated recognition of hazardous events during the execution phase. To achieve this, features of Bayesian Networks have been exploited. In addition, inputs to the model are assumed to be provided by a pervasive monitoring system deployed on the site. The need for this kind of intelligent tool is determined by the complexity inherent in construction sites, due to a variety of reasons, such as heterogeneity of the actors, the simultaneous nature of operations, harsh contextual conditions, and the only partially efficient current approach based on health and safety plans. Hence, this model is proposed as a support tool for health and safety coordinators for supervision of sites as they cannot guarantee a continuous physical presence.

Method Given that there are no long-time series on past occurrences of hazardous events in all the potential contextual combinations presently available, the probabilistic models cannot be learned just through datasets. For that reason, the available data have been integrated with expert opinions. In particular, the conditional probabilities of the Bayesian networks are estimated by an elicitation process of subjective knowledge from the opinions of experts. The complexity of the phenomena under analysis are modelled as a tree structure with several levels (corresponding to the work-breakdown structure hierarchy), which itself is based on the top-down technique; it provides therefore a clear view of the global picture. The built-hierarchical tree allows the expert to weigh more easily causal relationships involved and also to define the qualitative structure of the net. Furthermore, the article describes and tests how conditional probabilities of the variables in the networks can be estimated, through gathering and interviewing groups of stakeholders and experts.

Results & Discussion Our research has led to the definition of a probabilistic model using elicitation techniques for subjective knowledge. Furthermore, the development of such a model is part of a wider system relying on the implementation of a real-time monitoring network.

Keywords: Automation, health and safety, Bayesian networks, construction sites.

INTRODUCTION
The building trade appears as a sequence of subprojects, rather difficult to manage owing to: the variety and the heterogeneity of the involved players, the independence and the simultaneous nature of related tasks, the singularity and complexity of the final product, the specific productive and contextual conditions. Such features, along with other elements, represent a strong barrier to the development of a rational planning approach, and they dramatically affect safety in construction sites, as shown by the many worldwide statistics available in this field.

This paper reports the first results of an ongoing research project, which is aimed at implementing advanced probabilistic models for automatic real-time identification of hazardous events in construction sites. More specifically, the development of a Bayesian model for real-time health and safety management is carried out, which will be subsequently interfaced to a sensing technology to gather contextual information.

In the next section, practices and relevant undergoing research in this field are described, spanning from construction site accident statistics to inabilities of the actual safety management system, and including a general report about research advances in the field of real-time risk analysis. The third and fourth sections focus on the development of the Bayesian model using the elicitation approach from the subjective knowledge and experience of safety experts. The fourth section includes some demonstrations of the developed model in the running phase, too. The last chapter concludes and envisages possible future scenarios for this research, mainly devoted to the model implementation.

STATE OF THE ART

Construction site accident statistics
The number of accidents on building sites will help understand the efficiency and the results by the application of the most popular models for safety management.
A summary of national data on injuries at work shows that the construction industry is uppermost in the frequency of permanent disability or death. The number of accidents has decreased due to the economic crisis of recent years, along with the number of employed workers. The building sites are among the most dangerous workplaces and the number of accidents reaches up to 10-11% of the total reported in all manufacturing sectors. The number of accidents is higher in companies of handicraft character demonstrating the lack of organization and planning for health and safety.

The number of fatal accidents in European countries (EU 15) is decreasing in these years (less than 3 fatalities per 100,000 employed) but in the construction industry the number exceeds 10 fatal accidents per 100,000 employed. The most frequent cause of accidents in the building industry is fall from height. The main causes are the execution of tasks without proper scaffolding, work on the roof, falls from unprotected openings or inadequate scaffolding. A recent study tested a number of incidents occurred in fall from height from different manufacturing sectors, highlighting how the percentage of fatalities in construction industry exceeds 57% of the total accidents. The same study reported that 91% of fatal falls took place in commitments where handicraft companies (fewer than nine employees) were involved. In the Italian context a recent study on the causes of accidents based on a number of 460 cases of fatal accidents in 2011 showed a percentage of 22.2% for the construction industry and, with respect to the causes, a percentage of 23.9% due to fall from height of the worker. The study do not indicate, however, the accident dynamics: the analysis were conducted in regional context by heterogeneous methods.

In the U.S. construction industry one third of accidents are caused by fall from height. A study conducted by the Israeli Ministry of Labor and Welfare shows that 60% of accidents are due to fall from height and causes of these is in 41% by fall from slabs and roofs, in 19% fall from scaffolding and work surfaces, and 11% fall from ladders.

**Health and Safety management in construction**

Nowadays, the approach for health and safety management in construction industry is a standard practice in EU countries and it starts with the identification of tasks sequences at the design phase. Then, elementary working activities and preventive or protective actions are defined to safeguard workers. During the execution phase, an appointed Safety Coordinator is in charge of assuring the planned level of safety. In USA, in recent years, the NIOSH (National Institute for Occupational Safety and Health) promoted the PtD strategy (prevention through design) as a standard that provides guidance on including prevention through design concepts within an occupational safety and health management system. Thanks to the application of these prescriptions, decisions pertaining to occupational hazards and risks can be incorporated into the process of design and redesign of work premises, tools, equipment, machinery, substances, and work processes including their construction, manufacture, use, maintenance, and ultimate disposal or reuse. Both approaches (i.e. European and American standards) are based on the analysis of risk scenarios for each task and interfering activities expected in construction sites. Both models follow the PCDA cycle (Plan Check Do Act):

- Step 1: hazard and risk identification;
- Step 2: classification of risks in order of priority;
- Step 3: definition of preventive and protective measures for all risks;
- Step 4: taking action to mitigate and reduce risks;
- Step 5: check and review of drawn up safety plan.

The strength of the model lays in the ability to schedule the tasks time durations and the chance to reduce them to limit high-risk interferences. A weak aspect of the approach lays in the high costs tied to monitoring and control. Safety controls and checks, presently, imply strong, continuous physical presence of the Safety Coordinator on different construction sites in order to preserve the planned level of safety.

**Recent research and advances in real time risk analysis**

Statistics related to fatal/severe accidents on construction sites show that such places are still today the most dangerous ones. Besides causing human tragedy, construction accidents also delay project progress, increase costs, and damage the reputation of contractors. For this reason, a systematic control of operations is needed, which would however entail high costs defined "unsustainable" by some players. Safety controls and checks at present imply strong, continuous physical presence on the different work...
sites. There is an urgent need to develop methods allowing a cut-down in control costs through automatic alarm systems, warning hazardous situations potentially prone to degeneration into life and serious hazards, allowing for corrective operations in real time. A vast scientific literature regarding the development of technologies and methodologies to automatically support health and safety management is available. Even if supplying the complete list of works being performed in the field is a tough task, some of the most representative ones will be cited in this section. Instruments have been experimented on certain sites, different from construction sites because more structured with specific safety requirements (such as oil product refineries) which allow having real time knowledge of the position of workers present on the site. This has improved the situation involving interference between operators even if, in any case, only within the limits of surveillance delegated to an operator who is always present at the control boards.

Other systems for reducing risks regarding workers being run over by site equipment have been experimented as, for example, UWB radar systems installed on dumpers used in caves. Following another approach a 3D model is carried out starting from the data acquired by a LADAR (Laser Detection and Ranging) scanner so as to recreate the bulk of heavy objects present on the site and collision avoidance procedures. In this specific case, the approach was successfully validated but within the limits posed by the availability of an unobstructed visual filed, which is not always guaranteed on a construction site. Some years ago a compulsory safety helmet required for all workers in construction sites was enhanced to accommodate miniature positioning and communication instruments. A different approach to safety is the substitution of human labor with machines to perform dangerous tasks: one example is given by the specially designed light-weight robotic tool, for the application of advanced composite materials and epoxy resins during tunnel excavation. Another system against man-hook crane collisions was conceived: it starts from modeling workspace requirements related to mobile crane operations, and discerning the existence of spatial conflicts. Then it makes project engineers and operators aware of possible spatial conflicts ahead of time, so that they can accordingly take necessary preventive actions. A lot of effort was focused on fall hazards too. A mobile sensing device (i.e. transmitter sets and repeaters for sending information to a receiver) for detecting the worker’s approach towards floor openings was proposed. An automated procedures that identifies dangerous activities in the project’s schedule at the design stage was set up; it also defines the areas in the building where these hazards appear and proposes protective measures. The contribution given by ICT devices is critical for data gathering and immediate elaboration, but two pre-conditions have been recognized as critical for the success of ICT applied to safety: tracking systems must be low-intrusive and, also, they must be able to gather information in real-time, overcoming the limitations connected to manual information retrieval and handling, which has potentials for delays and errors. For that reason an ultra-wideband (UWB) wireless and untethered network system for mobile asset tracking at a dynamic construction site was tested. Its untethered nature favored the easy sensor nodes frequent relocation usually needed while work progresses. In addition, it avoids hazardous interferences between the network cables connecting all sensors on the floor or ceiling and crews engaged in material delivery and installation. The performances of this new UWB system were good, at the expense of a bit loss of accuracy, with respect to the basic tethered UWB system. Combining non invasive tracking systems with dedicated intelligent control logics, would make the automation of many important tasks for construction sites feasible.

A PROBABILISTIC MODEL FOR REAL TIME RISK MANAGEMENT: A BAYESIAN NETWORK TO SUPPORT SAFETY IN CONSTRUCTION

In this paper the progress status of our research, which is aimed at implementing advanced probabilistic models for real time identification of risk situations in construction sites, is reported. To this purpose the features offered by Bayesian networks are exploited. There are two main sources of information from which a Bayesian network can be developed: data and expert opinions. In this paper the Bayesian network was worked out by means of an elicitation process from the subjective knowledge of experts, in order to overcome the lack of data sets. As in the field of health and safety in construction there are no long time series on past occurrences of hazardous events in all the potential contextual combinations presently conceivable, the probabilistic models cannot be trained through just datasets. For that reason, the paper shows how the few available data have been integrated with expert opinions. The complexity of the problem under analysis are modelled as a multi-layered tree structure (corresponding to the Work Breakdown Structure hierarchy), which is based on the top-down technique; it provides therefore a clear view of the global picture. The built hierarchical tree allows the expert to weigh more easily causal relationships involved and to define the qualitative structure of the net, too. Furthermore, the article describes and tests how conditional probabilities of the variables in the network can be estimated, through gathering and interviewing groups of stakeholders and experts.
In Fig. 2, a flowchart is used to sum up all the process phases which led to the definition of the network described in this paper.

**Problem analysis**

De-structuring the building process: work breakdown structure

When the building process is represented as a tree structure with several levels (Work Breakdown Structure), following the top-down technique, the outcome is a cascading representation, that defines all its elementary components in details (WPs, like in Fig. 3).

Fig. 3. Tree-like decomposition (W.B.S.)

The development of the WBS and its efficacy in a process are straightforwardly affected by the level of accuracy used to identify all the components of the building process. As soon as the required level of appropriate accuracy is reached the decomposition process is over. It is worth noticing that the decomposition level varies according to the characteristics of the work to be carried out. In fact it is correct to say that the WBS can be divided into any number of levels, according to the intervention complexity, nevertheless, if the destructuring is extreme, it is difficult to keep track of the work progress, particularly if it has a long-term planning.

The built hierarchical tree allows an effective and deep understanding and control of the process regarding the safety aspects.

Following the analysis in detail of the building process and its de-structuring into elementary components, procedures and purpose of experts involvement have been defined. Furthermore, a model, which is aimed at gathering information from all the experts, has been developed. The model provides, to the experts, a guidance in eliciting process and, at the same time, it allows the analysts to gather homogeneous information.

**Elicitation process of subjective knowledge: expert opinion**

In this section of the paper, the elicitation process from subjective knowledge is shown.

Selecting experts: session A

In order to develop the Bayesian model, 6 experts have been selected. This selection led to set up a team with expertise in the field of safety management in construction sites. The table below shows the list of the experts involved and their specific contribution.
Fig. 4. List of the experts involved

Following the selection phase, all the documents about the problem (WBS, WP and related information) have been gathered and circulated among the involved experts. The objectives of this step are to ensure that everyone involved has the same information pertinent to the problem.

Defining causal model: session B
Once all the documents have been analyzed, the experts were asked to specify all the activities which are necessary to create each defined elementary component (WP) and, for each activity, they have defined some parameters like machines, materials, equipment but also the labor required to carry out every task (Fig. 5). On the basis of these parameters the linked risks have been identified. The experts gave back this information using the model defined above.

The article showed, in the section “state of the art”, that the most frequent cause of accidents, in construction sites, is fall from height (it represents almost 50% of fatalities). For that reason, our research project is focused on “fall from height risk” and the experts were asked to define the main dynamics about it. The outcomes of this phase were:
- fall from scaffolding,
- fall from carpentry/formworks,
- fall from roof.

Information and knowledge gathered in this first phase have been successfully summarized through “cause and effect” diagrams (see Fig. 6). These diagrams have been proposed during the following brainstorming phase as the tools for a structured discussion.

By mean of a first general questionnaire, the experts were asked to reflect individually about each risk scenario identified previously. In this way each expert was given the time to think about the problem and to develop his opinion before debating with the other experts. The aim of this first questionnaire is to give to a quiet individual as much prominence as a dominating one.
Learning probability distribution for all uncertain variables of the model: session C

Expert opinions of the uncertainty of parameters has been determined through one-to-one interviews. After a suitable period for contemplation following the brainstorming session, we have carried on individual interviews with all the experts to determine their opinions about the qualitative structure of the model and the uncertainty in each variable. In this way each expert has been given the time to think about the problem and to develop his opinion after debating with the other experts.

Beginning from the qualitative structures of the net, the experts were asked to define, individually, a first information set related to:
- the states of all the network nodes;
- equations which allow to formalize links between variables in the model.

Information gathered in this phase have allowed us to create conditional probability tables for each part of the Bayesian network.

Beginning from the last node of the network “fall from scaffolding”, the first fragment has been analyzed (see Fig. 11).

In order to develop this part of the network, the information about all the states of each variable has been gathered, coming to the structuring of the table of conditional probabilities. In this case, the experts have defined the states “low”, “medium” and “high” for the variable “fall from scaffolding” and the states “not serious”, “serious” and “extremely serious” both
for the variable “Improper use of the scaffolding” and also for the variable “combination”.

When the table related to this first fragment of network has been structured, we have defined a questionnaire which was aimed at gathering the expert opinions about probability distributions of the variable “fall from scaffolding”. Each expert was allowed to fill in the table of conditional probabilities on the basis of his/her personal experience.

The second fragment of the network is related to “Improper use of the scaffolding”. In this case the experts defined the states “yes” and “no” both for the variable “Use of ladders” and for the variable “Load capacity of the board”. Then, the experts have specified the states of the variable “bulky material”. For this last variable, it was necessary to refer to the level of obstruction for the presence of bulky material on the scaffolding walk planks. In this case, expert opinions have led to define the following three states for the variable “bulky material”:

State1: 0%<PO< 30% low obstacle: Caution
State2: 30%<PO<60% medium obstacle: Danger
State3: 60%<PO<100% high obstacle: High danger

When the table related to this second fragment of network has been structured, we have defined another questionnaire in order to gather the expert opinions about probability distributions of the variable “Improper use of the scaffolding” (see Figs. 13 and 14).

Sometimes we have obtained different estimates by the experts. This is usually because the experts made differing assumptions or have different sets of information on which their opinions are shaped (Fig. 15).

The paper shows how we have approached the problem. We have used a Discrete (x_i, p_i) distribution where the x_i are the expert opinions and the p_i are the weights given to each expert.

In this way, once the tables of conditional probabilities of a specific variable have been gathered, we have combined dissimilar expert opinions and the result was obtained as a weighted table (Fig. 16).

The weights have been changed in relation to the specific part of the network. Each part of the net, in fact, requires different experience because it defines a particular aspect of the same problem.

With the same procedure all the other fragments of the network have been analysed, coming to the defining of a preliminary Bayesian model.
In order to reach a concerted and definitive structure of the Bayesian model, another brainstorming session has been conducted. In this phase each expert has been given the last possibility to suggest changes to the Bayesian model.

**NETWORK IMPLEMENTATION**

Once the Bayesian network has been developed, it is ready to be implemented on a real construction site. Prior to this step, which belongs to future research, in the following sub-section we will show that the whole network is sensitive to the inputs relevant for the risk level estimation. The network was implemented in the Hugin Expert™ software program. The second sub-section will assess on the feasibility of the network implementation for real-time warning in case of falling hazards: such an application asks for the availability of several kinds of input data, including on one hand the effective operational configuration of the site and on the other hand real-time inputs relative to workers behavior, weather conditions, etc.

**Preliminary tests**

The first scenario in Fig. 17 shows our network’s risk evaluation in case the task activity is executed compliant to regulations and there are no adverse weather conditions. The risk level is not so high in this case \(<\text{low}>=18.63\%, \ <\text{medium}>=23.39\%, \ <\text{high}>=57.98\%\).

In case outdoor weather favors heat stroke, due to high temperature (around 104°F) and high relative humidity, even if wind is still calm, Fig. 18 shows that the expected risk of falling from heights is noticeably increased \(<\text{low}>=14.46\%, \ <\text{medium}>=19.66\%, \ <\text{high}>=65.88\%\).

In the next scenario (see Fig. 19) we assume high wind intensity and the removal of fasteners, some of the vertical frames (weakening the whole steel frame of the scaffolding) and base plates under the scaffolding foot have been removed. Such a combination could lead to overall instability of the scaffolding and further increases the estimated risk level \(<\text{low}>=7.44\%, \ <\text{medium}>=15.56\%, \ <\text{high}>=76.89\%\).
Fig. 19. The third scenario where scaffolding instability is more likely.

Finally, another far worse scenario where the presence of bulky materials on the scaffolding walk planks is assumed, along with the use of ladders by workers and the aforementioned material is so heavy to overcome the admissible threshold of load bearing capacity, Fig. 20 depicts the very high risk figure of falling from height (<low>=3.71%, <medium>=7.49%, <high>=88.80%).

Fig. 20. The fourth scenario where even unfair workers behavior is assumed.

Assessment on the network utilization for real-time safety management
The network is ready to be implemented in a real-time application for safety management in construction sites, provided that sensors for inputs collection are designed and properly installed on site.

With respect to this aspect, Fig. 21 shows an assessment on the origin of input data. Input data indicated as “Type A”, refer to the weather conditions. Their variation could be immediately relieved by appropriate sensors and transmitted to the network in order to identify, in real time, possible risk scenarios.

Input data indicated as “Type B”, directly refer to the effective configuration of the scaffolding and of its components (fasteners, vertical frames, base plates, guard-rails, walk planks). The low possibility of a continuous human control about the regular disposition of all the components of the scaffolding, suggests, also in this case, to employ appropriate sensors which are able to identify, in real time, any deviations from the planned configuration of all the components of the scaffolding.

Input data indicated as “Type C”, provide information about static aspects of the scaffolding: the pressure on the supports and on the walk planks. The extreme difficulty to immediately recognize the overcoming of the admissible threshold of load bearing capacity, notwithstanding a great experience, suggests to employ a sensor set aim at monitoring, in real time, conditions prone to the overcoming of the load capacity of the scaffolding.

Input data indicated as “Type D” refer to workers behavior on the scaffolding. This kind of data could result from a human control (coordinator, scaffolding fitters, manager, etc.). Because workers behavior often dramatically increases the risk level of falling from height, a frequent control must be guaranteed.

For this reason, this kind of input data could come from technological solutions which are aimed at obtaining constant automated monitoring of all the operative tasks on the scaffolding. Anyway, the network should record locations of the main resources of the specific construction site (workers, equipments, materials) highlighting the main risk scenarios of falling from height.

Fig. 21. The overall Bayesian network.

If the highlighted nodes of the overall network (see Fig. 21) collect data from sensors, all the other nodes will perform real time risk analysis on the basis of subjective knowledge which has been gathered through the elicitation process of the expert opinion described in the previous chapter.

CONCLUSIONS AND FURTHER DEVELOPMENTS OF THE RESEARCH
The present approach to health and safety management of construction sites owns strong intrinsic limits: every programmatic action whose scope is to minimize the probability of risky situations, notwithstanding its accuracy, must deal with the unforeseeable nature of all the construction dynamics. Our research focuses on the development of a new methodology for the identification and mitigation, in
real time, of risk scenarios according to the real configuration of the construction site.

The methodological adopted scheme is based basically on two steps:
- one model for the identification and evaluation of significant risk situations (decision making support);
- the adoption of advanced sensors.

Hence data arriving from sensors would be evaluated, in real time, in order to identify relevant risk scenarios. This paper reports the first result of our research project: the development of a Bayesian model focused on the risk scenario “fall from height” and its preliminary tests.

The future developments of the project will focus on the identification of the related sensor technology for real time control. The sensors will allow to gather data sets related to contextual conditions (e.g. Fig. 7) showed how weather conditions can increase the risk of fall from height: directly acting on the operators - heat stroke, and/or acting on the conditions of usability of the scaffolding - raining may cause any operator to slide. Even localization and monitoring of workers behavior have been found to be determinant for risk level estimation.

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Assessment of sustainable construction in Lebanon

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Purpose One of the most critical contemporary issues is achieving and maintaining sustainable development, adapting the use of natural resources to provide for the needs of our rising populations without threatening the survival and quality of life for future generations. Sustainable construction, in particular, is a concept that is gaining importance all over the world and is gradually improving life for populations that recognize its importance. The current environmental degradation in Lebanon due to limited natural resources, population increases, and inefficient urban management, threatens the economic growth and the wellbeing of the people and thus dictates the urgent need for planning and taking action on a comprehensive environmental sustainability strategy. The main purpose of this research is to explore the Lebanese construction industry in order to evaluate sustainability achievements on both design and construction levels. This research also studies sustainability standards and practices implemented in some developed countries and in the surrounding region in order to better assess the current status of sustainability development and corresponding public awareness in the Lebanese construction market with respect to foreign industries. Based on the aforementioned, this research addresses challenges to sustainable construction in Lebanon and provides recommendations to enhance the use of energy-saving materials and the application of environmentally-friendly construction methods. Method This assessment is done through two complementary approaches: (i) a comprehensive literature review of all pertaining governmental regulations, public policy, and guidelines that have been enacted to promote building sustainability in Lebanon, as well as a survey about existing green buildings and ongoing green projects along with the implementation challenges; and (ii) conducting interviews with Lebanese parties that are key players in achieving sustainable development such as local experts, public agencies, municipalities, architectural and contracting firms, private agencies dealing with environment protection, and real-estate companies. Results & Discussion The concept of sustainable production and construction is still very primitive in Lebanon and the role of the government in promoting sustainability is not yet well established. Some public entities including, but not limited to, the Ministry of Industry, the Ministry of Environment, the Ministry of Energy and Water, the Council for Development and Reconstruction (CDR) have put some effort through internationally funded projects and campaigns by UNDP and the European Commission aimed at promoting sustainable production and consumption in Lebanon. However, these efforts were not enough to have a significant impact on these industries and resulted merely in voluntary guidelines rather than serious measures to reduce energy usage and pollution. Another finding of this research is that major efforts need to be made towards enhancing public awareness of sustainability issues. Hence, this research analyses the observed deficiencies in the Lebanese construction market and provides some recommendations that, if turned into action plans, constitute a promising transition from a short-sighted construction focusing on short-term goals of profit making and fast growth and lacking concern for the environment to a global long-term sustainable development that ensures the welfare of the current and future generations.

Keywords: Management and social issues, sustainability, public policy, construction practices.

INTRODUCTION
Lebanon has been undergoing a reconstruction and rehabilitation phase since 1990 which marked the end of a hostile 15-years civil war. This war has not only damaged the country’s infrastructure but moreover it has weakened its economy, depleted its natural resources and greatly polluted its environment. Additionally, Lebanon has been suffering from power shortage for the past twenty years and as a result private power generators became the main alternative for providing electricity to the population and consequently controlling the society’s quality of life. According to the United Nations Framework Convention on Climate Change, Lebanon’s energy use resulted in the emission of 12 million tons of CO₂ in 1994 of which 8% generated from energy used in buildings for heating and cooling purposes. According to the same report, the increase in CO₂ emissions reached 35% between 1994 and 1999¹. These facts highlight the urgent need for a major transition from a shortsighted construction focusing on short-term goals of profit making and fast growth and lacking concern for the environment and for scarcity of natural resources to a global long-term sustainable development that ensures the welfare of our current and future generations. The concept of sustainable production and construction is still very primitive in Lebanon and the role of the government in promoting sustainability is not yet well established. Some public entities including but not limited to the Ministry of Industry, the Ministry of Environment, the Ministry of Energy and Water, the
Lebanese Institute for Normalization (LIBNOR), and the Council for Development and Reconstruction (CDR) have put some effort through internationally funded projects and campaigns by UNDP and the European Commission that aimed at promoting sustainable production and consumption in Lebanon. However, these efforts were not enough to have a significant impact on the concerned industries and resulted merely in voluntary guidelines rather than serious measures to reduce energy usage and subsequent pollution. In particular, sustainable construction is starting to gain the interest of some developers in the Lebanese market but yet there is still a lot to be achieved in this field namely improving building codes to include more incentives for green construction and enhancing the legislative body to enforce these regulations.

This paper assesses the current status of sustainable development in Lebanon, particularly in the construction sector, and provides an extensive overview over pertaining laws and regulations. It also presents a wide perspective about international sustainability practices in some neighboring Arab countries and other Western countries in order to better understand where Lebanon stands on the international sustainable development scheme. The paper ends by identifying the different challenges the Lebanese industry faces and provides recommendations to enhance sustainable development and to promote green buildings in Lebanon.

**THE LEBANESE CONSTRUCTION INDUSTRY**

In the past couple decades, Lebanon’s environment has been deteriorating exponentially due to destructive exploitation of natural resources and to the pre-occupation of the government with political, financial, and economic matters. Forested areas which used to cover 13 % of Lebanon have decreased tremendously to only 5 % as a result of forest fires, cutting of trees and urbanization. Marine resources have suffered from extensive pollution all along the Lebanese coast and have revealed the presence of mercury and copper due to discharge of untreated wastewater and industrial waste. A national water quality survey conducted in 1990 indicated that approximately 70 % of all water sources were exposed to bacteriological contamination. Air pollution resulting from the combustion of petroleum products for power generation and transportation purposes has reached high-levels almost approaching the WHO health norms. Furthermore, most sand and gravel used in construction are obtained through removal of sand from the coastal strip and through quarrying in the mountains; which poses serious threats of intensive coastal erosion and morphology, and mountainous terrain erosion and landslides.

To address these environmental threats, Lebanon has undertaken several initiatives that are mandatory in paving the way towards a clean and sustainable environment. The Ministry of Environment (MoE) was established in 1993 (decree 216) to protect the environment and was amended in 2005 to address sustainability issues. For instance, giving protected status to some green areas consisting about 2 % of the total surface area, and improving solid waste collection and treatment in several parts of the country are some of the improvements made in this respect.

Furthermore, the MoE has enacted several laws to govern the protection of the environment in Lebanon. One of these laws is the Environmental Protection Law (decree 444) which addresses the importance of preserving the nature and the environment through setting a strategic national plan, revised every two years. The law dictates that a national environmental council representing the concerned ministries as well as expertise and NGOs working in the private environmental sector will be developing, implementing, and supervising the environment protection plan. The law also stresses the importance of increasing public awareness through introducing the concept of nature conservation into academic curriculums and organizing awareness campaigns, lectures, and symposiums. Furthermore, the law suggests incentives to encourage the population protect their environment through allowing up to 50% discounts on importation taxes corresponding to equipment or technologies that reduce or prevent environment pollution or that serve solid waste treatment. It also designates fines for each violation of the environment wellbeing. Another important initiative is decree 14865, enacted by MoE in 2005, where the ministry promises to make financial contributions to non-profit organizations to carry out environmental activities that enhance sustainable development including promotion of research in this field.

However, and despite all the environmental regulations that have been adopted by the Lebanese government, indicating the environmental maturity and awareness of the public authorities, the problem still remains in enforcing these legislations. A project led by UNDP in conjunction with the Ministry of Justice was approved in 2007 and aimed at improving the judiciary system of the Lebanese Ministry of Justice and building its capacity in enforcing environmental legislation. However, this project faced many challenges such as the lack of proper archiving and electronic filing of cases, and the lack of environmental law courses offered at the Lebanese universities. Thus, the project focused on introducing an environmental course at the Institute of Judicial training at the Ministry of Justice to help judges better understand the flaws of the current system and the ways it can be improved.
From the construction perspective, this paper conducted a comprehensive survey over the Lebanese building code and found out that it merely provides guidelines or minimal incentives towards achieving sustainable construction. For instance, the code specifies certain design guidelines for windows placement that enhances natural lighting and saves on power, and it allows for subtraction of wall areas from allowable area exploitation only if proper isolation is used like double glazing. Besides, the Ministry of Environment developed several laws that help protect the environment against the hazards resulting from construction activities. One such example is decree 8006 which regulates sanitary waste disposal methods. Another such important decree is the environmental law 444, developed in 2002, that stresses the importance of conducting an Environmental Impact Assessment (EIA) study for public and private buildings exceeding a certain built area. This EIA serves to analyze and reduce any negative impact a building might have on the environment, and to protect the safety of its inhabitants and visitors. But unfortunately, and similar to all other environmental regulations, EIA is not mandatory because it has not been enacted yet by the Council of Ministers. The decree stated that it would be enforced through specialized governmental controlling bodies which have not been formed yet and thus making the law ineffective.

One of the key players towards achieving sustainability in the Lebanese construction market is the Lebanese Green Building Council (LGBC) which is a non-governmental organization founded in 2008 to promote sustainability and the use of energy-saving materials for buildings. To serve its purpose, LGBC organizes sustainability awareness campaigns and evaluates the energy efficiency of buildings through its own developed rating system (ARZ) for green buildings. The ARZ rating system contains four levels of certifications with five-year validity that assess the efficiency of several components: orientation and structure design, energy, materials, water, building isolation, materials, indoor environmental quality, operation & maintenance optimization, and waste and toxics reduction. Although LGBC has been very active in promoting sustainable construction and despite the emergence of some NGOs that have the necessary expertise in tools and techniques required for green buildings (e.g., Lebanese Association for Energy Saving and for Environment, Green Hand, Green Line Association, Lebanese Solar Energy Society, etc.), the movement towards sustainable construction is still very primitive and the percentage of green buildings remains very minimal. Examples of current green projects under construction are Beit Misk which is a rural residential project targeting sustainability, and the Sama Beirut tower aiming for LEED certification. Another example is La Brocéliande, a residential project in the Beirut suburbs of Yarzé by Greenstone Real Estate Developers, which is the first to take into consideration the sustainability standards of the UK’s BREEAM rating system by using building components and construction practices that are energy efficient. However, these projects result merely from personal initiatives by developers or owners that are aware enough of the long term benefits of sustainable construction and are not enough to declare a sustainable construction pattern in the Lebanese industry.

Based on the aforementioned, it is observed that the main obstacle towards green construction is the fact that the current construction law does not take into consideration the environmental impact of design and construction aspects in buildings and hence does not firmly enforce an environmental impact assessment for each project to study and control its effect on the nature. The other main concern, and beside the lack of proper legislation system with adequate monitoring agencies, is the lack of public awareness about the importance of sustainable development and preservation of the nature’s resources. A survey conducted by UNDP showed that only six out of fifty universities in Lebanon include courses about environmental laws and policies in their undergraduate curriculums. Thus, a critical and promising step towards achieving sustainability is raising awareness of the public about the benefits of sustainable construction through organizing more campaigns and updating our educational curriculums to teach the new generation about the environment and the relevant regulations. Once real-estate buyers or end users become knowledgeable about green buildings and their benefits, it consequently influences developers and contractors.

**Sustainability in Foreign Countries**

**Arab Countries in the Middle East Region**

Sustainable development is recently becoming one of the top concerns in the Middle East region. According to a study conducted by Merrill Lynch, one of the world’s leading financial management and advisory companies, around 20% of the wealthy investors in the Middle East region, have already invested in green related technologies. In fact, green building councils have been established in most of the Arab states, and while some rely on previously established rating systems such as LEED, others create their own rating systems such as the ARZ system in Lebanon, Estidama in the United Arab Emirates and the QSAS in Qatar. On the other hand, the UNDP has been active as well through a comprehensive plan on the regional scale to help the Arab countries save their environment threatened by water scarcity, desertification and other concerns. The UNDP has been working...
closely with governments through its Country Office to tackle certain problems on the national level: combating desertification, improving water management, mobilizing funding from the Global Environment Facility, and taking an integrated approach to climate change.

Zooming further into the wealthier countries of the region, the United Arab Emirates exhibits a fast growing economy exposed to extreme heat conditions and desertification risks. This makes the conservation of energy vital and a strategic planning to reduce the environmental harm essential. On the bright side, the UAE benefits from a high GDP and a strong commitment to environmental duties making it one of the leading countries in strategic planning within the Arab countries. Unlike Lebanon, an increased wealth resulting from the extraction of natural oil allowed the UAE to invest in developing and implementing environmental regulations to varying degrees according to each emirate. Also, the UAE ratified several international conventions such as the Kyoto Protocol and the United Nations Convention to Combat Desertification, which shows its commitment to preserve the environment. Besides, the Emirates Green Building Council (EGBC) plays a key role in protecting the environment and in raising public awareness.

Among the United Arab Emirates, Dubai is taking a leading edge towards sustainable construction. In fact, the Government of Dubai, Dubai Electricity & Water Authority, and the Municipality of Dubai coordinated the creation and implementation of the "Green Building Regulations & Specifications". This code, inspired by the LEED system, is applicable to all the buildings in Dubai and targets areas such as ecology and planning, building vitality, and resource effectiveness in terms of energy, water, material and waste. Accordingly, more than 300 buildings are certified to be green today in Dubai alone.

As for the emirate of Abu Dhabi, its Urban Planning Council (UPC) has introduced a framework for sustainable design, construction and operation under the name of Estidama Pearl Rating System. All new buildings, villas, and government-owned and operated buildings are required to achieve a minimum sustainability score under the Pearl system. The Masdar development project, a sustainable city designed to house 50,000 people in a green environment with an investment of almost 25 billion USD, is the highlight of Abu Dhabi's commitment to sustainable development.

On the other hand, Qatar who is living a period of economic prosperity and construction boom has been also one of the leading countries in the Arab region in the sustainability field. Qatar has combined regional and international certification systems into one comprehensive system, the Qatar Sustainability Assessment System; tailored to the country's conditions and vision. Furthermore, and according to the Ministry of Environment, the QSAS and the Qatar Building Standards of 2010 (QBS) should be applied to all public buildings in Qatar as well as residential and commercial complexes. Another huge leap towards leadership in sustainability is the fact that the country has started its project to host the 2022 World Cup in 12 stadiums presenting zero carbon impact and relying on solar power for all functions. This would definitely become an inspiring incentive for the region.

Saudi Arabia is another country in the Arab region exhibiting a high GDP and gaining further interest in sustainable development. Several initiatives were taken by the kingdom, most importantly, the adoption of the Green Building- EcoSENS program that aims to raise awareness and provides training for local engineers for the LEED certification program. Also, new buildings for Princess Noura University and the Ministry of Higher Education are applying LEED standards. The Saudi Green Building Council is also playing an important role in spreading awareness and providing a platform for various construction sectors to facilitate green construction.

Other countries of the Arab world, with a GDP similar to Lebanon, remain at an early stage of reaching sustainability, notably Jordan. Many efforts are put into the matter, and the Jordan Green Building Council has been established in 2009 taking part of the World Green Building Council. This organization is supported by the USAIDS and has been working on creating standards and recommendations while spreading awareness throughout the country. The campaign is fully supported by the royal governing family along with the concerned ministries. Additionally, other bodies such as the Jordan Engineers Association are working closely with other regional bodies such as the Gulf Organization for Research and Development to promote sustainability. A promising initiative towards green construction is the development of Al-Mushatta Industrial City that aims to become the first green industrial city in the region. While these initiatives enlighten the public about the importance of sustainable development, Jordan, and similarly to Lebanon, suffers from the lack of a proper judiciary body that can implement and enforce environmental legislations.

Egypt is another neighboring country to Lebanon that is also at a preliminary stage of launching and implementing a strategic sustainable development plan. The Egyptian Green Building Council was established in 2009 encouraging the implementation of already existing codes aiming to preserve the environment, combat desertification, and reduce energy consumption in buildings. For this purpose, the council developed the Green Pyramid Rating System which is similar to the ARZ system in Lebanon by
LGBC but accustomed to fit the Egyptian environmental needs and building requirements. Several initiatives have been studied and considered by EGBBC that highlight the interest of developers in sustainable projects. Examples are the Eco-villages National Project approved by the Minister of Housing, Utilities and Urban Communities, the Affordable Green Housing project that aims to create sustainable homes for middle income families, and the New Hermopolis, a new resort capable of housing 52 visitors that runs purely on ecological principles.

Another important incentive towards sustainability is the construction of the HSBC buildings in Cairo according to the LEED standards. However, and according to developers of these projects, the main challenge to advancing in sustainability remains the absence of enacting and enforcing proper environmental regulations.

Based on the aforementioned, the Arab countries are clearly divided into high and low income governments. And it is well observed that this particular status reflects on the development and implementation of strategic plans towards sustainability. This may be due to the elevated immediate cost of investing in sustainability, or even the fact that awareness comes hand in hand with the buying power of the government and its capacity to reflect on environmental considerations.

**Western Countries**

In contrast with most developing countries that are still taking the initial steps towards achieving sustainable development, many of the developed countries are past this stage to a more mature phase where sustainability standards and regulations have been enacted and implemented, and are in constant change for the better.

For instance, there are many bodies in the United States of America that contribute to the implementation of sustainable development, most importantly the Environmental Protection Agency (EPA) which issues laws and regulations, compliances and enforcements. The EPA addresses the construction sector by monitoring air pollution, waste, and other hazardous pollutants resulting from construction. Many building codes are issued according to the specific conditions of each region or state. The most recent one is the “2012 International Green Construction Code” issued by the International Code Council and sponsored by the American Institute of Architects and by US green building council. This code constitutes a regulatory framework for new and existing buildings that establish sustainability requirements from the design phase to the construction phase and operation of the building9. Another regulating body aiming for the same goal is the US Department of Homeland Security which issued the “2011 Strategic Sustainability Performance Plan”.

This plan works on studying lifecycle costs for new buildings while assessing environmental, economical and social aspects. Besides, there are several non-governmental organizations that provide major efforts to raise public awareness and encourage the green industry, the most important of which is the USGBC which provides consulting, monitoring and environmental impact assessment services for buildings through the LEED certification program. This certificate has become very popular over the years to expand over 120 countries, including Lebanon.

As for the United Kingdom, the government is directly involved in assisting and planning sustainable development. The Code for Sustainable Homes and the Energy Performance Certificate (EPC) for Construction set the minimum requirements for buildings in order to attain sustainability (energy and water efficiency). The code for sustainable homes is an environmental assessment rating method for new homes that evaluates the environmental performance of a building during design and post construction phases. The environmental impact of a building is measured according to nine categories including energy and carbon emissions, surface water runoff, water use, materials, waste, pollution, etc. This code is mandatory for all new dwellings and the assessment results are recorded on a certificate assigned to the dwelling9. Also, the EPC for construction targets both homes and commercial buildings. The evaluation targets energy reduction within appliances including heating, air conditioning and ventilation. Obtaining the certificate is required according to the building code. Besides, the “Sustainable and Secure Buildings Act 2004” is another legislation among many others that put the UK’s on the right track towards achieving sustainability.

On the other hand, the European Union Member States have also formulated their long-term strategy to achieve economic, social and environmental sustainable development and have set certain targets to reach by 2020. Along its sustainability plan, the European Commission has issued many policies and legislations impacting the construction industry some targeting the energy efficiency of buildings, control over hazardous construction materials and others addressing workers’ conditions. Among these regulations are the Waste Framework Directive which aims at providing a better management of wastes resulting from the construction industry, and the Energy Efficiency Package aiming at reducing energy consumption10. These frameworks emphasize the importance of monitoring construction products by classifying and regulating dangerous substances used in the construction industry such as chemicals, waste issues, indoor emissions, soil and groundwater releases, etc.

Moreover, the European Commission has put into action several incentives that encourage its states
and their local governments to improve their environment and commit to sustainable development. One of these initiatives is the European Green Capital award which is granted to the city that has the highest environmental standards and which can be a role model that inspires other European cities to compete for sustainability. For instance, both Nantes (France) and Vitoria-Gasteiz (Spain) were the winners of this price for 2012. Another such incentive is the One Billion Euros research investment entitled “Energy-Efficient Buildings” and financed jointly by EC and the industry. This programme was launched in July 2009 and aims at promoting the integration of green technologies and energy efficient materials in new buildings in order to reduce CO₂ emissions and save on energy usage.

To summarize, it is clear that Western countries are taking a huge leap towards achieving sustainability due to the complementary efforts of their governments and non-governmental agencies. They mostly exhibit a dynamic platform for green construction supported by public awareness and a legislative body that ensures the orientation of the industry in the proper direction.

**CHALLENGES TO SUSTAINABLE CONSTRUCTION IN LEBANON AND RECOMMENDATIONS**

In comparison with sustainability development in the surrounding Arab countries, U.S, U.K. and the European Union member states, Lebanon seems to have taken some primitive steps towards the sustainability plan but a lot remains to be achieved yet so it can take a place among the leading countries in this field.

Besides the scarcity of its natural resources, Lebanon has suffered from a long civil war that lasted about 15 years and thus brought the country under a heavy financial debt and hindered its economic growth. In fact, only 2.4 % of total public financial resources are allocated to environmental protection11. And of course green construction requires higher immediate investments than ordinary one which makes convincing developers and users of opting for sustainable construction a challenge. Here comes the importance of public awareness and recognizing the benefits of lower life cycle costs of green buildings. Thus it is mandatory to teach our generations about our environmental concerns, the importance of preserving our natural resources, and the urgent need to develop and enforce environmental regulations in order to protect our environment. Hence, green construction technologies and their effect on the environment as well as building codes and regulations should be introduced into our Civil Engineering curricular programs. Also, the media (visual or written) should help promote sustainability by dedicating enough time or space to talk about environmental issues, show their impact on our daily lives, and discuss the ways they can be addressed. In addition, the private and public sectors should both coordinate and create incentives to orient developers and users towards sustainable development such as discounts on environment-friendly materials and green construction technologies, rebates on solar panels, reduced interest on loans for green houses, etc.

Another major barrier threatening the sustainable development in Lebanon is the lack of a proper legislative system responsible for enforcing and monitoring green construction practice. While the Ministry of Environment along with the Ministry of Energy and Water are trying to spread awareness through campaigns and other initiatives, the absence of a solid building code or regulations along with the absence of a credible monitoring agency represent the most challenging threat yet to overcome. The government plays a key role in this regard and should at least enforce the minimum requirement of submitting an environmental impact assessment for new buildings to the corresponding authorities for approval. It should also ensure that at least public projects use components and construction practices that are energy efficient and environmentally sustainable so they provide a role model for the private sector. Another incentive that the government can initiate is to organize a Green City Award, similarly to the European Commission, in order to motivate Lebanese cities to compete for sustainability.

Last but not least, cooperation and coordination of efforts between the governmental parties such as the Ministries of Environment, Industry and Public Works, the Council for Development and Reconstruction, the different NGOs such as LGBC and others, the developers, the educational and training institutions and the public is a crucial factor to face the current challenges and to put the country on the right and fast track towards sustainability.

**CONCLUSION**

This paper presented a detailed assessment of the sustainability aspects of the construction sector in Lebanon discussing the pertaining environmental regulations, in particular the construction law, the contribution of concerned NGOs and the few applications of green construction in the market. Then, it provided an extensive review of the international sustainability practices and their implementation in surrounding Arab countries and in some other developed countries in order to have a better perspective of the Lebanese sustainability efforts. This paper concluded by identifying the challenges towards promoting green construction in Lebanon and provided recommendations that help turn the sustainability development plan into reality.
References
The Impact of ICT Use on Loneliness and Contact with Others among Older Adults

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Purpose
Older adults are at increased risk of experiencing loneliness and depression, particularly as they move into different types of care communities. Information and communication technology (ICT) usage may help older adults to maintain contact with social ties. However, prior research is not consistent in whether ICTs increase or decrease isolation and loneliness among older adults. The purpose of this study is to examine how ICT use impacts the social isolation and loneliness of older adults in assisted and independent living communities.

Method
Data from an ongoing study of ICT usage among older adults in assisted and independent living communities in Alabama is used. Simple regression analyses were performed to determine the relationship between frequency of Internet use and isolation and loneliness. As the data comes from an intervention study (ICT training vs. No training), the analyses controlled for the arm of the study participants were in.

Results & Discussion
Results from post intervention surveys show that going online more frequently was associated with lower levels of loneliness and isolation. Greater frequency of Internet use was associated with greater quantity and ease of contact with others. Using the Internet may be beneficial for decreasing loneliness and increasing social contact among older adults in assisted and independent living communities.

Keywords: older adults, loneliness, social contact, social isolation, ICT

INTRODUCTION
As individuals age, they may lose contact with social network members for a variety of reasons. This loss of contact is often associated with social isolation and loneliness. Some research has shown that information and communication technology (ICT) use may help to decrease social isolation and loneliness in older adults. The purpose of this study is to examine how frequency of going online among residents of independent and assisted living communities (AICs) is related to experiences of loneliness and social isolation.

BACKGROUND
The concepts of loneliness and social isolation are closely related concepts, yet highly nuanced. Loneliness is the subjective experience of negative feelings about levels of social contact, otherwise stated, it is the involuntary state of social isolation, that is, the feeling of being alone. Loneliness does not stem solely from objective levels of contact, but rather results from the differences between the levels of need and desire for social relationships and the availability of relationships at hand. Researchers using loneliness measures typically ask respondents whether they feel lonely, whether they do not see enough people, and whether they wish for more contact.

Social isolation is the objective experience of the absence of contact with other people; more aptly stated, it is the absence of good support. Social isolation is simply the absence of meaningful social relationships or the experience of being alone.

Older adulthood is often associated with higher rates of loneliness and social isolation. This occurs for a variety of reasons, including death of social ties, relocation to different types of living and care communities, and limitations in physical and mental health. In addition, age is negatively related to network size, closeness to network members and number of primary group ties. Older African Americans are at the greatest risk of social isolation, along with childless individuals and widows. Those at risk for loneliness include older adults who have recently migrated following retirement, those caring for a dependent spouse, the chronically ill, those living alone, and females living in rural communities. Although the likelihood of experiencing loneliness does increase with age, only a minority of older people continuously suffer from loneliness. A noteworthy finding is that loneliness does not increase simply because of additional years, but because of an increase in disability and a decrease in social integration. The only risk factors applying to both the socially isolated and lonely are living alone and having low life satisfaction. In sum, predictors of social isolation and loneliness are not necessarily interchangeable, which demonstrates the need for researchers to distinguish between the two concepts.

Older adults are at risk for increases in loneliness and social isolation, particularly for those who move
to different types of care communities. Research shows that older adults who move into assisted and independent living communities are likely to experience reduced quality of life. They are likely to experience loss of social connections, physical separation from familiar places and routines, and resulting emotional distress that can combine to affect the mental and physical health of residents. A wealth of research indicates that ICT use by older adults can both strengthen and expand their social networks and social connections, with relationships taking place both on and offline. ICT use can also reduce the impact of geographic distance for older adults, with dispersed families increasingly using ICTs as the primary conduit through which they sustain generational bonds.

Whether ICT use increases or decreases social isolation is not clear-cut, however. ICT has been shown to be associated with a decrease in social isolation and increases in social connectivity among older adults. Use of the Internet has been shown to enrich the lives of isolated seniors, with some older adults reporting lower perceived life stress as a result of ICT use.

Yet, some limited research has found no relationship between Internet connectedness and social isolation in older adults. Another study of the general population demonstrated that Internet use had a relatively limited impact on social relationships, with still other research indicating that ICT use was associated with an initial decline in social network size and increased loneliness. However, a follow-up study done in 2002 showed Internet users experienced positive effects on communication, social involvement, and well-being.

The purpose of this study is to examine whether frequency of ICT use among older adults is associated with perceptions of (1) loneliness, (2) social isolation and (3) perceptions of the usefulness of the Internet in affecting quantity and quality of communication with social network ties.

**METHODS**

The data for this analysis comes from an ongoing randomized controlled trial intervention. In this study, assisted and independent living communities (AICs) were randomized into ICT, Attention Control, or True Control groups. Older adults living in AICs in the treatment arm were given 8 weeks of training in using computers and the Internet to communicate with family and friends (mainly through email and Facebook) and to find information. Participants in an “attention control” arm were involved in 8 weeks of activities unrelated to ICTs. Participants in a “true control” arm did not participate in any intervention activities. Participants from all three arms were surveyed 5 times over the course of one year – before the 8 weeks, at the end of the 8 weeks, and at 3, 6, and 12 months after the end of the 8 weeks. Because the purpose of this paper is to examine the relationship between ICT use and outcomes such as loneliness, social isolation, and perceptions of the usefulness of the Internet for staying in touch, ICT users (participants with Internet access) from all three arms are included. Additionally, because there were such low numbers of ICT users at time 1, across the three arms (n=33), post-test (immediately following the 8 weeks) data is used, reflecting all the relatively new ICT users in the ICT arm of the study. Thus, our sample includes all study participants who reported having Internet access, either on their own or as a result of the ICT intervention classes (n=70).

Our outcomes include how use of the Internet has affected loneliness, social isolation, and the quality and quantity of communication with others. Loneliness was measured with a 3-item version of the UCLA loneliness scale. Items in the scale (a=.65) were:

a. How often do you feel that you lack companionship?
b. How often do you feel left out?
c. How often do you feel isolated from others?

with responses measured on a three point scale: 1-Hardly ever, 2-Some of the time, 3-Often.

To measure social isolation, participants were also asked how much of the time they were bothered by the following things:

a. Not having a close companion
b. Not having enough friends
c. Not seeing enough of the people you feel close to.

The responses were coded as 0-Never, 1-A little of the time, 2-Some of the time, 3-Most of the time, 4-All of the time. These items were analyzed individually.

Participants were asked a series of 7 questions regarding their perceptions of how Internet use had
affected the quality and quantity of their communication with others. Participants were asked to what extent they agreed or disagreed with the following statements: Using the Internet has . . .

a. Made it easier for me to reach people
b. Contributed to my ability to stay in touch with people I know
c. Made it easier to meet new people
d. Increased the quantity of my communication with others
e. Made me feel less isolated
f. Helped me feel more connected to friends and family
g. Increased the quality of my communication with others.

The responses were coded as 1-Strongly Disagree, 2- Disagree, 3-Neither Agree nor Disagree, 4-Agree, 5-Strongly Agree.

ICT use was measured simply as frequency of going online. Participants were asked how often they went online with 0 coded as Never, 1-Once every few months, 2-About once a month, 3-Severals times a month, 4-About once a week, 5-Several times a week. Only participants who reported having Internet access were included in the analysis, as those reporting no Internet access were not asked about their perceptions of how Internet use has affected their communications with others.

A series of OLS regression analyses were conducted using the communications and loneliness as the primary outcomes and using ICT use as the primary predictor variable. Analyses controlled for age, the number of social network members (friends and family to whom the participant felt close), study arm, and physical or emotional problems that would limit social interaction. While we would normally have controlled for race/ethnicity and gender, these controls were not included here as an overwhelming majority of the sample was white and female.

RESULTS
As noted, our sample was overwhelming white (95.7%) and female (81.4%), with a mean age of 84 years (full descriptive statistics are presented in Table 1). The mean frequency of going online was 3.41 (somewhere between ‘several times a month’ and ‘about once a week’). Mean loneliness was 3.9. The sample contained 49 participants who had received ICT training and 21 who had not.

Results of OLS regression analyses showed a relationship between the frequency of going online and socio-emotional outcomes and between frequency of going online and selected Internet-usefulness outcomes. Among the socio-emotional outcomes, a one-point increase in the frequency of going online was associated with a .220 point decrease in loneliness scores (p<=.001) (full results presented in Table 2). After controlling for the number of friends and family, physical/emotional social limitations, age, and study arm, the association remained, with a one-point increase in the frequency of going online being associated with a .236 point decrease in loneliness scores.

Table 1. Descriptive Statistics (n=70)

<table>
<thead>
<tr>
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<th>Mean (SD) or Percentage</th>
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<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18.6</td>
</tr>
<tr>
<td>Female</td>
<td>81.4</td>
</tr>
<tr>
<td>Age</td>
<td>84.0 (6.1)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>95.7</td>
</tr>
<tr>
<td>Other</td>
<td>4.3</td>
</tr>
<tr>
<td>Frequency of Going Online</td>
<td>3.4 (2.0)</td>
</tr>
<tr>
<td>Loneliness</td>
<td>3.9 (1.2)</td>
</tr>
</tbody>
</table>

Likewise, going online more often was associated with a decrease in the amount of time respondents were bothered by not having a close companion and by not seeing enough of the people they are close to. A one-point increase in online frequency was associated with a .153 point decrease in the amount of time respondents were bothered by not having a close companion. Both of these associations were statistically significant at the .05 level. Similarly, a one-point increase in online frequency was associated with a .189 point decrease in the amount of time respondents were bothered by not seeing enough of the people they are close to. This relationship, too, held in the presence of the controls with a one-point increase in frequency of going online being associated with a .198 point decrease in the amount of time respondents were bothered by not having enough close friends.

Among the Internet outcome measures there were only two relationships of note, both of which were statistically significant at the .05 level before controls, but which barely missed the .05 cutoff in the presence of controls (full results presented in Table 3). In terms of agreement with the statement
### Table 3. OLS Regressions (Using the Internet has . . .) (n=54)

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
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<tbody>
<tr>
<td>Constant</td>
<td>3.05***</td>
<td>4.78**</td>
<td>2.82***</td>
<td>4.60**</td>
<td>2.17***</td>
<td>4.07*</td>
<td>2.71***</td>
<td>4.30**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency of Going Online</td>
<td>.171</td>
<td>.095</td>
<td>.241*</td>
<td>.194†</td>
<td>.168</td>
<td>.113</td>
<td>.249**</td>
<td>.194†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Family/Friends</td>
<td>- .037</td>
<td>- .017</td>
<td>- .041</td>
<td>- .029</td>
<td>- .029</td>
<td>- .017</td>
<td>- .041</td>
<td>- .029</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>- .018</td>
<td>- .019</td>
<td>- .022</td>
<td>- .017</td>
<td>- .018</td>
<td>- .019</td>
<td>- .022</td>
<td>- .017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In AC Group</td>
<td>- .916</td>
<td>- .308</td>
<td>- .508</td>
<td>- .479</td>
<td>- .916</td>
<td>- .308</td>
<td>- .508</td>
<td>- .479</td>
<td></td>
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</tr>
<tr>
<td>Model F</td>
<td>2.68</td>
<td>1.95</td>
<td>6.91*</td>
<td>1.74</td>
<td>2.17</td>
<td>1.13</td>
<td>7.23**</td>
<td>2.20</td>
<td></td>
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<tr>
<td>R²</td>
<td>.03</td>
<td>.10</td>
<td>.10</td>
<td>.08</td>
<td>.02</td>
<td>.02</td>
<td>.11</td>
<td>.12</td>
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Note: Unstandardized coefficients presented.  
†p < .10, *p < .05, **p < .01; ***p < .001.
<table>
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<th>Model 1</th>
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<th>Model 1</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.39***</td>
<td>4.98**</td>
<td>3.53***</td>
<td>3.82**</td>
<td>3.56***</td>
</tr>
<tr>
<td>Frequency of Going Online</td>
<td>.094</td>
<td>.054</td>
<td>.109</td>
<td>.049</td>
<td>.057</td>
</tr>
<tr>
<td>Number of Family/Friends</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Physical/Emotional Social Limitation</td>
<td>- .048*</td>
<td>- .014</td>
<td>- .003</td>
<td>- .023</td>
<td>- .124</td>
</tr>
<tr>
<td>Age</td>
<td>- .023</td>
<td>- .000</td>
<td>- .003</td>
<td>- .059</td>
<td>- .046</td>
</tr>
<tr>
<td>In AC Group</td>
<td>- .689</td>
<td>- .901</td>
<td>- .394</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In ICT Group</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model F</td>
<td>.778</td>
<td>1.18</td>
<td>1.68</td>
<td>1.33</td>
<td>.395</td>
</tr>
<tr>
<td>R²</td>
<td>.00</td>
<td>.02</td>
<td>.01</td>
<td>.04</td>
<td>-.01</td>
</tr>
</tbody>
</table>

Note: Unstandardized coefficients presented.

† p ≤ .10, ¶ p ≤ .05, ** p ≤ .01, *** p ≤ .001.
that “using the Internet has contributed to my ability to stay in touch with people I know”, a one-point increase in the frequency of going online was associated with a .241 point increase in agreement that the Internet had contributed to the ability to stay in touch. This association was statistically significant at the .05 level. Once controls were included, however, the relationship was weakened such that a one-point increase in online frequency was associated with a .194 point increase in agreement with the statement that the Internet had contributed to the respondents’ ability to stay in touch (p. = .054).

A similar change occurred in the analysis of respondents’ agreement with the statement that “using the Internet has increased the quantity of my communication with others.” Before controls a one-point increase in the frequency of going online was associated with a .249 point increase in agreement that the Internet had increased the quantity of communication. The relationship was statistically significant at the .01 level. Once again, after the inclusion of controls, the relationship weakened, with a one-point increase in online frequency being associated with a .194 point increase in agreement that the Internet had increased the quantity of the respondents’ communication with others. This relationship, with controls, also missed the cutoff for statistical significance, with an exact p-value of .051. Frequency of going online was not associated with a change in agreement with the statements that using the Internet had “made it easier to reach people,” made it easier to meet new people,” “made me feel less isolated,” “helped me feel more connected to friends and family,” or “increased the quality of my communication with others.”

DISCUSSION AND LIMITATIONS

Results of this study suggest that the frequency of going online impacts loneliness and perceptions of social isolation, with higher frequency being associated with lower levels of loneliness and social isolation among older adults in assisted and independent living communities. These results support prior research showing that Internet use positively impacts quality of life among older adults.5,9,10,35,36,39 However, it is interesting that older adults in this study do not perceive that using the Internet has made it easier for them to reach people, meet new people, helped them to feel more connected to friends and family, or increased the quality of their communication. They do, however, perceive that using the Internet has contributed to their ability to stay in touch and has increased the quantity of communication with others. The results of this study suggest that further research is needed to better ascertain when older adults in different types of living communities may perceive and actually receive the most benefits from using a variety of types of ICTs.

Limitations of the current study include the small sample size, the lack of diversity in terms of gender and race/ethnicity, and that the study was only conducted in assisted and independent living communities in Alabama. Further research is needed on how technology usage may impact older adults not living in AICs and how these processes may vary as a function of gender, race/ethnicity, severity of health impairment, and region of the country.

In sum, this research indicates that Internet usage has positive benefits for older adults living in assisted and independent living communities. Given that this population experiences high rates of loneliness and depression, encouraging older adults to begin using the Internet to communicate with others could help to enhance social contact and decrease loneliness and social isolation.

References


Purpose  Renewable energy components such as Building Integrated Photovoltaic (BIPV) often influence the aesthetic quality of a building adversely and hence need to be analyzed for their impact on building form and aesthetics. This becomes crucial especially in the case of a sun-tracking photovoltaic system. Moreover, there is a need to propose a reasonably accurate but quick system to estimate the amount of solar insolation received by a given location. Both the visualization of BIPV’s movement and the solar insolation calculation can be integrated into a Building Information Model (BIM) to help design professionals to assess the feasibility of various solar photovoltaic options. Method A solar insolation model proposed by Kumar and Umananda is used to develop a BIPV prototype in a BIM platform (Autodesk Revit). A graphical user interface is developed to input the time and location information. Results & Discussion A BIPV-prototype is developed to calculate solar position and determine the amount of solar insolation from given time and location information. The proposed model can be integrated into BIM to automatically calculate the solar position and the amount of solar insolation based on user inputs of time and location. We plan to compare this prototype with PV F-chart method. We will also research the use of Modelica for creating PV-component models and integrating the PV-modeling into thermal and daylight modeling. Keywords: information technology, BIM, solar insolation, clearness index, BIPV

INTRODUCTION
Among current trends in architectural design is to introduce sustainability by either applying energy saving strategies or incorporating renewable energy options. One dilemma faced by building designers is to create a balance between aesthetics and technology. One among most practiced is the Building Integrated Photovoltaic (BIPV) that involves integrating solar cells or modules into the building components such as walls, canopies, roofs etc.1, 2. Studies suggested that BIPVs not only facilitate generating renewable energy but also, protect buildings from heat, cold and rain3. Furthermore, BIPVs may be more cost effective if they replace building components such as wall cladding panels, roof slates, light shelves, sun-shades etc. Renewable energy components such as solar photovoltaic (PV) panels often influence the aesthetic quality of the building adversely and hence, need to be analyzed for their possible impact on building form and aesthetics. Studies3, 4, 5 suggested considering both technological and aesthetic factors while integrating such renewable technologies into a building. The maximum power conversion efficiency of a typical solar module (monocrystalline) is 14-17%5 and hence; maximizing its power would require optimizing PV orientations over daily sunshine hours. This may be possible by designing and installing sun-tracking BIPV modules that are integrated into a building as building components such as roof tiles. For a better understanding of the orientation of a sun tracking solar module at a given time it becomes important to visualize their movement throughout the day. Furthermore, it is also important to make sure that these panels do not cast shadows on each other2.

The solar insolation data become crucial for analyzing solar PV applications for economic and functional feasibility. The insolation data can be either measured at a given location or can be procured from a meteorological agency both of which could be expensive and time consuming6. According to Kumar and Umananda6, for a widespread application of Solar PV system, a straightforward and quick method to calculate the global solar insolation at any given location is crucial. This paper focuses on developing a BiPV prototype by integrating an Application Programming Interface (API, of Autodesk Revit as a sample BIM platform) into a BIM for calculating the orientation of a sun-tracking PV roof tile/panel. In addition, the solar insolation model proposed by Kumar and Umananda6 is used to develop a mathematical model for calculating direct global solar insolation in North America. In the future, this model will be added to the BiPV prototype developed in Autodesk Revit.

OBJECTIVES
The research is aimed at, developing a BiPV prototype to calculate the orientation of sun-tracking solar PV roof tiles/panels and validating the model proposed by Kumar and Umananda6 for locations in North America. The following are the main objectives:
To develop a BiPV prototype in a BIM platform (Autodesk Revit) to calculate the solar orientation
To develop and validate the global solar insolation (direct component) model for locations in North America

RESEARCH METHODS
A parametric family for the sun-tracking solar PV roof tiles is developed and integrated into a generic residential building model in Autodesk Revit. The orientation of solar PV roof tile is governed by solar altitude and azimuth angles. The altitude and azimuth angles can be calculated using the latitude, longitude, time and day information. An API is developed and integrated into the parametric family to perform the solar altitude and azimuth angle calculation. A graphical user interface helps the user in entering latitude, longitude, time and day information. The API performs the calculation and sets the calculated values to the altitude and azimuth of the parametric family to show the solar orientation.

The extraterrestrial direct solar insolation can be calculated for a given location and time. The actual amount of direct global insolation received at a location depends upon a stochastic parameter called the sky clearness index, which is a function of time and geographic location. The seasonal and climatic conditions vary with time of the year and geographic location and affect the value of clearness index. The solar insolation model proposed by Kumar and Umananda\(^6\) is based on the latitude, precipitable water vapor in the atmosphere and day of the year data. Such information is easily available for most of the locations around the world\(^6\). The measured values of sky clearness index are used to calculate Fourier coefficients that help curve fit the plot of clearness index versus the day of the year. Kumar and Umananda\(^6\) developed and validated the model for locations in India between 0-32 degrees (North) latitudes.

We developed and validated a mathematical model using the same approach for North American locations between 0-32 degrees (North) latitudes. Table 1 provides the list of twelve locations with latitude information that are used in developing the model. The measured values of sky clearness index, precipitable water vapor and global insolation are sourced from the NASA Surface Meteorology and Solar Energy website\(^7\). Three locations other than the ones included in the model development are selected in the United States of America for validation.

FINDINGS
Figure 1 illustrates the parametric solar PV roof tile family developed in Autodesk Revit. A graphical user interface (as shown in Figure 1) collects the latitude, longitude, time and day information and calculates the solar orientation. It also modifies and shows the position of solar PV roof tiles based on the calculated altitude and azimuth values.
sourced from the NASA website. Figures 2, 3 and 4 illustrate the measured and calculated direct global insolation for 12 months for the three locations. It can be seen that the calculated direct global insolation values are within 0.18 – 9.22% of the monthly averaged measured values. Such error is reasonable for the preliminary assessment of a solar PV system for a given location.

Table 2. Calculated (K_cal) and measured (K_meas) values of sky clearness index at locations of validation

<table>
<thead>
<tr>
<th>Month</th>
<th>Jacksonville</th>
<th>Dallas</th>
<th>Brunswick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.69</td>
<td>0.7</td>
<td>0.69</td>
</tr>
<tr>
<td>Feb</td>
<td>0.69</td>
<td>0.71</td>
<td>0.7</td>
</tr>
<tr>
<td>Mar</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Apr</td>
<td>0.69</td>
<td>0.7</td>
<td>0.68</td>
</tr>
<tr>
<td>May</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
</tr>
<tr>
<td>Jun</td>
<td>0.64</td>
<td>0.63</td>
<td>0.64</td>
</tr>
<tr>
<td>Jul</td>
<td>0.62</td>
<td>0.62</td>
<td>0.64</td>
</tr>
<tr>
<td>Aug</td>
<td>0.63</td>
<td>0.63</td>
<td>0.64</td>
</tr>
<tr>
<td>Sep</td>
<td>0.64</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Oct</td>
<td>0.67</td>
<td>0.66</td>
<td>0.67</td>
</tr>
<tr>
<td>Nov</td>
<td>0.69</td>
<td>0.68</td>
<td>0.7</td>
</tr>
<tr>
<td>Dec</td>
<td>0.69</td>
<td>0.69</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 3. Calculated (In_cal) and measured (In_meas) values of direct global insolation (KWh/m^2) at locations of validation

<table>
<thead>
<tr>
<th>Month</th>
<th>Jacksonville</th>
<th>Dallas</th>
<th>Brunswick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>4.05</td>
<td>4.13</td>
<td>3.75</td>
</tr>
<tr>
<td>Feb</td>
<td>5.07</td>
<td>5.11</td>
<td>4.77</td>
</tr>
<tr>
<td>Mar</td>
<td>6.23</td>
<td>6.26</td>
<td>5.94</td>
</tr>
<tr>
<td>Apr</td>
<td>7.18</td>
<td>7.2</td>
<td>6.92</td>
</tr>
<tr>
<td>May</td>
<td>7.56</td>
<td>7.39</td>
<td>7.33</td>
</tr>
<tr>
<td>Jun</td>
<td>7.72</td>
<td>7.28</td>
<td>7.42</td>
</tr>
<tr>
<td>Jul</td>
<td>7.64</td>
<td>7.03</td>
<td>7.26</td>
</tr>
<tr>
<td>Aug</td>
<td>7.16</td>
<td>6.64</td>
<td>6.69</td>
</tr>
<tr>
<td>Sep</td>
<td>6.21</td>
<td>6.04</td>
<td>5.83</td>
</tr>
<tr>
<td>Oct</td>
<td>5.14</td>
<td>5.15</td>
<td>4.85</td>
</tr>
<tr>
<td>Nov</td>
<td>4.18</td>
<td>4.26</td>
<td>3.96</td>
</tr>
<tr>
<td>Dec</td>
<td>3.75</td>
<td>3.77</td>
<td>3.49</td>
</tr>
</tbody>
</table>

CONCLUSIONS

An API was developed and integrated into a generic residential model built in Autodesk Revit to calculate and show the orientation of sun-tracking solar PV roof tiles. It is found that the movement of solar PV tiles can be accurately modeled using a parametric family in BIM. Such a tool can help architects and design professionals to visualize the orientation of solar PV tiles to balance the aesthetics and technology in architectural design. We also developed and validated a solar insolation model based on the method derived by Kumar and Umananda. It was concluded that such mathematical model can calculate the sky clearness index and direct global insolation in a given location with a ±10% error (over measured data). The model utilized easily available information such as latitude and precipitable water vapor in the atmosphere to compute the direct component of global solar insolation.

FUTURE RESEARCH

We plan to integrate the developed solar insolation model into BIM so that not only the solar orientation but also the amount of solar insolation can be calculated with a reasonable accuracy (error within 15% of the measured values). Moreover, a model for other latitudes will also be developed and validated to extend the scope of API to other locations around the globe. We also plan to include the calculation of diffused and scattered component of the global insolation in the proposed model.
ACKNOWLEDGEMENT
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References
**SIMPLIT: Ensuring technology usability for the elderly**

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1 Instituto de Biomecánica de Valencia, Universitat Politècnica de València, Spain

* Corresponding author (juan.dura@ibv.upv.es)

**Purpose** The aim of this work is to establish a reliable methodology to test if a product is simple, practical, and user-friendly for the elderly. We pursue a twofold objective: (i) to respond to companies that want to be responsive to this increasingly demanding group; (ii) to guarantee that the certified products are easy to use for the elderly. The methodology will consist of reliable protocols according to the quality required by the recognised certification bodies-in the Spanish case AENOR.  

**Method** The method we followed involves several steps: (i) assure the participation of elderly people with the collaboration one of the most important Spanish elderly associations: UDP 1.500.000 members; (ii) a field study (441 questionnaires) to obtain and classify the problems that elderly people experience with products; (iii) define testing protocols based on the fulfilling mandatory standards and usability tests. Usability tests are based on a hierarchical classification of tasks and a categorical classification of the problems. We obtained data on the effectiveness, efficiency and ease of learning, with which elderly people achieve specified goals in particular environments; (iv) checking the process with 4 practical cases that cover low-tech and hi-tech products: the wardrobe, an activity park, an oven, and a tablet computer; (v) submitting protocols satisfying the requirements of a quality certification body.  

**Results & Discussion** As result we have developed a methodology with four steps. (i) Verification of the regulation (standards). We check compliance with the legislation on safety and ergonomics of the product to guarantee that it fulfills the minimum conditions. (ii) Ease-of-use tests. We analyse the learning of tasks, ease-of-use and efficacy of implementation, performing a diagnosis of the product based also on the assessment of elderly users. (iii) Global product diagnosis. (iv) Quality verification. We make sure that the product diagnosis is performed systematically by audit of the certification body (AENOR). The assessment of effectiveness, efficiency and ease of learning, are tasks classified on 4 levels: (a) basic & high frequency, (b) basic & low frequency, (c) no basic & high frequency, (d) no basic & low frequency. The problems that appear during the tasks are classified in 18 categories (e.g. dexterity, reaching, equilibrium, etc.). This problem classification facilitates the search for solutions and helps designers to improve the design. This methodology has resulted in a new certificate: SIMPLIT. SIMPLIT is a quality label that guarantees that products have been developed with a design aimed at elderly people. This certificate is now being used and several products have obtained the quality label. Moreover, we use the methodology in projects to develop new products for the elderly.  

**Keywords**: usability, certification, effectiveness, efficiency, ease of learning

**INTRODUCTION**  
Older population has become a powerful consumer group, accounting for 26% of all retail sales. This population group is growing, and its impact on the Spanish society is becoming more and more important. Currently, it represents approximately 6.7% of the total population, but it is estimated to rise over 30% by 2050. However, more than 80% of the older persons believe that Spanish companies never, or hardly ever, have them in mind when it comes to designing their products.

Older persons detect serious problems regarding the usability of many products. This often leads to falling into complete disuse or not taking advantage of their full functional potential. Design focusing on older people allows achieving age-friendly products. The aim of this work is to develop a certificate that certifies that a product is comfortable, intuitive and easy to use.

**METHODOLOGY**  
The methodology is divided in two main blocks. The methods used in order to identify problems and products categories. And the methods used in order to define the protocols.

**Identification of problems and product categories**  
Firstly, a field survey with standardized open-ended interviews (the same open-ended questions are asked to all interviewees) with 500 old persons (Table 1) and 350 stores. The goal of the interviews is to obtain information in order to define a map that relates products categories and problems. The definition of the interviews is based in focus groups with older people and the collaboration of one of the most important Spanish older persons associations: UDP 1.500.000 members (www.mayoresudp.org).
The older persons that participate in the field survey live independently in their homes. The field survey covers different sizes of cities (Table 1).

<table>
<thead>
<tr>
<th>City size</th>
<th>Age</th>
<th>Women</th>
<th>Men</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2,000</td>
<td>50-65</td>
<td>14</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>65-80</td>
<td>12</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>2,001-10,000</td>
<td>50-65</td>
<td>23</td>
<td>22</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>65-80</td>
<td>19</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>6</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>10,001-50,000</td>
<td>50-65</td>
<td>27</td>
<td>25</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>65-80</td>
<td>22</td>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>&gt;50,001-500,000</td>
<td>50-65</td>
<td>34</td>
<td>32</td>
<td>66</td>
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<tr>
<td></td>
<td>65-80</td>
<td>29</td>
<td>23</td>
<td>52</td>
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<tr>
<td></td>
<td>&gt;80</td>
<td>9</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>&gt;500,000</td>
<td>50-65</td>
<td>32</td>
<td>30</td>
<td>62</td>
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<tr>
<td></td>
<td>65-80</td>
<td>27</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>9</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>TOTAL</td>
<td>275</td>
<td>225</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Distribution of stores

<table>
<thead>
<tr>
<th>Store</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drugstore</td>
<td>47</td>
</tr>
<tr>
<td>Appliances and electronic devices</td>
<td>90</td>
</tr>
<tr>
<td>Clothes and textiles</td>
<td>102</td>
</tr>
<tr>
<td>Shoes</td>
<td>19</td>
</tr>
<tr>
<td>Kitchen Furniture</td>
<td>47</td>
</tr>
<tr>
<td>Furniture</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>350</td>
</tr>
</tbody>
</table>

The objective of the interviews is to obtain information about problems of use of products, and the type and the importance of the problem. The problems are classified by means of semantic differential.

Definition of SIMPLIT protocol

The test protocol for any type of product is based on a preliminary definition of the problems related with the use, compliance with standards and recommendations related to the problems, and test with 8-10 users. The test with users includes two techniques: task analysis and think aloud.

During the first phase, the product must comply mandatory regulations such as Electromagnetic legislation for electronic devices or specific directives of each product or application field.

Moreover, a group of four experts agrees the minimal accessibility and usability requirements of the product based on scientific literature and standards, including Spanish, European and ISO standards. The experts assess the accomplishment of minimal requirements taking into account the expected use and basic tasks of the product, and its relation with the physical, sensorial and cognitive capabilities of older persons.

The product compliance with obligatory regulation and minimal usability requirements is mandatory to start the second phase.

During the second phase, the first step is to define the experimental design: user characterization, taking into account the target group of the product, and definition of the basic of regular use, basic of non-regular use and secondary tasks of the product.

Before start the usability tests, users perform a set of functional test to ensure that fit with user characterization. The observer provides a brief explanation about product use, only for products of Group 1 and 2. Users have three repetitions to correctly perform each task: the first repetition without help, the second repetition with support of product instructions and the third repetition with support of verbal instruction of the observer. Moreover, in the case of products of Group 1 Table 3, if users need to perform the third repetition, they must perform a fourth repetition without any kind of help to demonstrate that they know how to perform the task.

During user tests, the observer records task accomplishment, spent time, errors (type, frequency and seriousness of problems), need of support and number of repetitions needed for the successful fulfillment of the task. Finally, the observer makes a personal interview to the users to obtain qualitative information about their opinion of the ease of use of the product, advantages and disadvantages.

The third step is to process the recorded data to assess the effectiveness and efficiency of each task based on task accomplishment, spent time and number of errors, and number of repetitions. The success threshold of each parameter depends on product category.

Finally, a product gets the SIMPLIT certificate based on the effectiveness and efficiency of the basic tasks. The effectiveness is prioritized over efficiency and the tasks with regular use over the tasks with non-regular use.

Moreover, the product receives a rating from 1 to 5 "stars" depending on its performance level, which depends on the percentage of efficient basic tasks and the percentage of effective and efficient secondary tasks.
Validation of SIMPLIT protocol
We have tested the protocol with four practical cases that covers low-tech and hi-tech products: wardrobe, activity park, oven and mobile telephone.

This has allowed adapting the test protocols in order to pass the conformity assessment of a quality certification body (www.aenor.es).

RESULTS
Map of products and problems.
The products have been classified in 5 categories with different characteristics (Table 3): technology level, need of instructions, need of learning, number of body functions or body parts that interacts with the product (Interaction level), and personal use (only for group 5).

Table 3: Products categories

<table>
<thead>
<tr>
<th>GROUP</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>High technology</td>
</tr>
<tr>
<td>Examples:</td>
<td>Low interaction</td>
</tr>
<tr>
<td>Mobile phone</td>
<td>Instructions required</td>
</tr>
<tr>
<td>Home automation device</td>
<td>Learning required</td>
</tr>
<tr>
<td>Group 2</td>
<td>Medium technology</td>
</tr>
<tr>
<td>Examples:</td>
<td>High interaction</td>
</tr>
<tr>
<td>Oven</td>
<td>Instructions required</td>
</tr>
<tr>
<td>Microwave</td>
<td>Learning required</td>
</tr>
<tr>
<td>Group 3</td>
<td>Low technology</td>
</tr>
<tr>
<td>Examples:</td>
<td>Medium interaction</td>
</tr>
<tr>
<td>Bed</td>
<td>No instructions</td>
</tr>
<tr>
<td>Shower</td>
<td>No learning</td>
</tr>
<tr>
<td></td>
<td>Use in basic activities</td>
</tr>
<tr>
<td>Group 4</td>
<td>Low technology</td>
</tr>
<tr>
<td>Examples:</td>
<td>High interaction</td>
</tr>
<tr>
<td>Knife</td>
<td>Instructions required</td>
</tr>
<tr>
<td>Glass</td>
<td>No learning</td>
</tr>
<tr>
<td>Group 5</td>
<td>Low technology</td>
</tr>
<tr>
<td>Examples:</td>
<td>High interaction</td>
</tr>
<tr>
<td>Clothes</td>
<td>Instructions required</td>
</tr>
<tr>
<td>Glasses</td>
<td>No learning</td>
</tr>
<tr>
<td></td>
<td>Use in basic activities</td>
</tr>
<tr>
<td></td>
<td>Personal equipment</td>
</tr>
</tbody>
</table>

The types of problems for each product category are:

Table 4: Type of problems

<table>
<thead>
<tr>
<th>Problems</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>To reach in height</td>
<td>2, 3</td>
</tr>
<tr>
<td>To reach deep</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Bending, Maintain posture</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Force (push and pull)</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>Force (use of controls)</td>
<td>2, 3, 4, 5</td>
</tr>
<tr>
<td>Mobility (push and pull)</td>
<td>2, 3, 4, 5</td>
</tr>
<tr>
<td>Coordinate movements (simultaneous actions)</td>
<td>2, 3, 4, 5</td>
</tr>
<tr>
<td>Dexterity (hands)</td>
<td>All</td>
</tr>
<tr>
<td>Dexterity (rotate and press)</td>
<td>All</td>
</tr>
<tr>
<td>Security (bumps and cuts)</td>
<td>2, 3, 4, 5</td>
</tr>
<tr>
<td>Read signs (size, understanding, contrast)</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Memorizing steps (illogical, complex)</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Lack of feedback</td>
<td>1, 2, 3, 5</td>
</tr>
<tr>
<td>Read instructions (font size, contrast)</td>
<td>1, 2, 5</td>
</tr>
<tr>
<td>Understand instructions (illogical, complex)</td>
<td>1, 2, 5</td>
</tr>
</tbody>
</table>

Validation of the protocol
The validation of the protocol was performed with the four practical cases (wardrobe, activity park, oven and mobile telephone) comparing user tests with heuristic evaluation performed by four experts on usability and older people.

The reliability of the methodology was checked comparing the tests results performed with two set of users and four observers during the assessment of each product. Moreover, the protocols have passed the conformity assessment of AENOR.

The results of these tests allowed adjusting the success thresholds of effectiveness (task accomplishment) and efficiency parameter (spent time, number of errors, necessity of support and number of repetitions).

CONCLUSIONS
A reliable methodology has been set up, combining expert assessment with user tests, to assess the ease of use of any product by older persons. We have applied SIMPLIT process to more than 20 products covering from mobile telephone, tablets, software, furniture, kitchen equipment to telecare systems. Until now, six products have obtained the SIMPLIT certificate.

In parallel, we have launched a set of dissemination activities to inform older person and companies about the SIMPLIT certificate. Moreover, we have carried out some formative initiatives to train older
persons to assess, choose and buy products fitted to
their needs and capabilities.

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Risk communication design for older adults

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INTRODUCTION
As the baby boomers approach the age of retirement, older adults have become the fastest growing demographic in United States. Currently people over 65 form 13% of the population. This is expected to increase to 20.7% by 2050. Financial assets owned by older adults are consequently proportionally increasing. One-tenth of all publicly held bonds are held by people over 65 years of age. By 2020 older adults will own one-third of all publicly held stocks in America. Older adults are, however, highly susceptible to scams and financial fraud. According to the Federal Trade Commission, over 20% of the victims of financial fraud are older adults. This susceptibility to victimization is likely to be transferred online.

Older adults are increasingly using the Internet to manage their financial assets. However, they have traditionally been underserved by the designers of technology. The current design of technologies assumes a high level of computer literacy and agile cognitive abilities. Conversely, older adults are disproportionately inexperienced with information technology. They have less cognitive reserve and plasticity than younger cohorts. As such they may be unaware of the many risks they face when they go online. Thus a combination of misperception of risk, poor understanding of technology, and age related cognitive changes might either prove a deterrent to adoption or expose older adults to undesirable risks. There is limited research examining older adults’ understanding of the risk generated by their digital data with respect to financial privacy and security.

We propose to address this knowledge gap by creating a model of older adults’ understanding of their digital footprint and financial risk. Thus, in this study we wanted to address two research questions. First, what is the effect on comprehension when using videos as opposed to text? Second, what are the determinants of older adults’ perception of online risk, specifically for responding to phishing and malware e-mails? We conducted pilot studies with a convenience sample of 12 older adults (8 female and 4 male). Six participants watched the videos, the other six read the textual description of the risks, and each filled out associated surveys.

Results & Discussion
All 12 participants rated the risk of responding to be higher than that of not responding, but not all items on the five dimensions were rated higher for responding. This indicates that not all dimensions have equal weights in the construction of perceived risk. Participants in the video group were more likely to verbalize the risk of responding or not responding, suggesting videos might be better at explaining online risks to older adults.

Keywords: communication and governance, security, older adults, risk communication
identify determinants of risk perceptions for older adults. These determinants can then inform the design of risk communication technologies targeted towards older adults. Our goal is to enable older adults to identify, mitigate, and avoid risks to their financial assets and personal identity. Identifying determinants of risk perception would allow designers to ensure that the information contained in risk communication is pertinent, aligned with the elder's mental model, and informs decision-making. This is particularly important for older adults as they proportionally suffer from increased sensitivity to irrelevant intrusions and are less able to selectively attend to information. In this paper, we present the design of narrative-driven risk communication videos that leverage physical mental models to inform older adults about online risks. The two risks we target are phishing and malware. The next section provides the background and describes the rationale for our approach.

**BACKGROUND**

Misperception of risk, limited understanding of information technology, and age-related cognitive changes leave older adults vulnerable to a host of financial crimes. Financial loss can be more distressing for elders than their younger counterparts, as elders have limited time and ability to recover financially. With the ubiquity of the Internet, financial exploits can now be conducted by unidentifiable electronic assailants from distant jurisdictions. As recovery becomes more difficult, prevention is increasingly crucial. Individual resilience to social engineering attacks has been addressed by providing security education to non-experts, e.g. phishing education. The participants in these studies, however, are usually younger adults who may differ from older adults in their ability to assimilate new information. We propose to build upon these works by addressing a demographic group that differs in its cognitive plasticity and technological experience. Furthermore, our approach addresses risk communication as a complement to security education. Education may be a longer-term effort that requires a higher cognitive commitment. It can be argued that the primary goal is to change behavioral reaction to risk rather than to explain the underlying mechanism. The latter might be particularly difficult for online risks that are novel and abstract. This becomes even more problematic for older adults who may be less experienced with technology and thus less aware of the risks. Here risk communication can mediate education by facilitating behavior change. Therefore, there is a need to design risk communication technologies geared towards near-term behavioral change in older adults.

If risk communication is to be effective, its design must address the target demographic. There has been limited research in designs targeted specifically towards older adults. Designing for older adults is not the same designing for a generic end user. Aging has an effect on memory, cognition, and attention, including the older adults' ability to process information. Older adults, for example, can be overwhelmed by the information they are exposed to, if both the visual and the audio channel are simultaneously being used to communicate different information. Fisk et al. recommend design guidelines for instructional technologies targeted towards older adults. They advocate against overload of sensory channels and avoidance of irrelevant data, while advocating for allowing time to reflect and internalize the material presented. The underlying rational for these recommendations is to meet the needs of older adults who experience age-related cognitive changes. In general, episodic memory deteriorates more quickly than semantic memory. However, there are advantages to episodic memory. Older adults are more likely to retain content than context. This context is provided by episodic memory. Older adults also suffer disproportionally from irrelevant intrusions, i.e. when faced with a decision they are less able to determine the pertinent information that should occupy the working memory than when they were younger. This retrieval of pertinent information is better in episodic memory than semantic memory. Thus, there are several advantages to using techniques that trigger episodic memory. These advantages consist of richer comprehension and contextualization as well as efficient and pertinent information retrieval.

Videos, rich in multi-sensory information, trigger episodic memory. Video-based narratives can provide richer comprehension than text. Videos are coded in the episodic memory as compared to text, which is coded in the semantic memory. Episodic memory, though richer, requires more memory blocks. Thus while retention periods may be smaller, videos can provide better understanding, for example of how security and privacy risks are realized online. Since episodic memory in older adults deteriorates more quickly than semantic memory, the assumption that videos would provide richer comprehension is largely untested. However, recent studies in cognition have been promising.

Another component of risk communication is using the appropriate mental models. Mental models refer to internalized representations of external reality. Camp states that security experts predominantly use five mental models: physical, criminal, medical, warfare and market. Mental models of end users are not always aligned with security experts. End users find physical/criminal mental models to be the most accessible. Physical mental models can both lever-
age the affect heuristic as well as providing grounding of abstract online risks in a more tractable context.

Thus, our approach towards risk communication in this study combines insights from studies on cognition and mental models to develop video-based narratives grounded in physical analogies. Furthermore, we include risk mitigation and risk avoidance strategies in these video and text communications.

**VIDEO DESIGN**

In this section we give a description of the video design. We sought to design videos that leveraged physical/criminal mental models. Thus, we developed narratives that use analogies from the physical world to convey virtual risks. The two risks we targeted were phishing emails and malware, in particular key loggers. These risks were chosen due to their strong financial impact. Research shows that the annual loss due to phishing, and possible gain to phishers, is $178.1M a year\(^1\). Malware also has significant financial impact. Small and mid-sized companies lost up to $40M in 2009 due to malware in United States.

The videos were designed to be a narrative with three parts:

1. Risk awareness: We show how someone might fall victim to a risk like a phishing or malware email.
2. Risk avoidance/Risk mitigation: We show how the victim can avoid or mitigate the risk by demonstrating alternatives to accepting the risk.
3. Risk in context: In (1) and (2) we used narratives based in physical analogues. In the third part we demonstrate how a similar scenario might play out online and bridge the gap between the offline analogy and the online risk. We also provide statistics to convey the severity of falling victim. Finally, we provide links to more information.

Fisk et al.\(^{14}\) provide guidelines for designs targeted towards older adults. Some of our design decisions were contrary to the recommended guidelines. We found that providing both visual and audio stimuli at the same time would be preferable in a narration-based setting. Subtitles can be used and indeed add to the ease of comprehending the video. Though subtitles provide the same information as the audio, they may be important for older adults who may suffer from impaired hearing.

**Phishing**

Phishing involves a criminal entity masquerading as a legitimate trustworthy entity to procure an individual’s private information. So we took an example phishing email and presented it in two versions, text and video:

**Text Version:**

We used an example email:

Dear Mr. Cullen, We are from the IRS and we are writing regarding your retirement funds and bank accounts. It has come to your attention that there might be some discrepancies with respect to some of the transactions made from your accounts. We are conducting an investigation into this. We would like to get some information from you. Please click on the link at the bottom of the email and answer a few questions. Please make sure that you have your bank account number, password, and your social security number as you may be asked about them. www.IRS.com

Regards IRS

**Video Version:** Based on these characteristics we designed the physical narrative for the phishing video. We had an older adult pose as a target of the scam. We had an attacker who was dressed in a suit pretending to be an IRS agent. The agent carried credentials that appeared authentic. The agent came to the house of the older adult and informed him that he was under investigation due to financial discrepancies. The agent then asked for the older adult’s financial information. In the first scenario the older adult, wanting to comply with the investigation, provided the information and thus was phished. In the second scenario the older adult refused to provide information until he could confirm the existence of the financial discrepancies. The older adult then called his bank to inquire about the said discrepancies and whether he was being investigated. Thus he discovers that the agent was a fraud. Finally we establish the connection between the physical analogy and the online risk, as shown in Fig. 1.

![Fig. 1. Phishing websites, like the fake agent in our video, appear to be legitimate.](image-url)
Malware
Malware is malicious software. It is hard to detect once installed and can potentially log critical authenticating information and send it to the attacker. Similar to the phishing emails, we had to identify the key characteristics of emails that encourage users to download malware.

Text Version:
We used an example email:
Dear Mr. Cullen, You have a secret valentine. Your secret love has sent you a singing telegram. To listen to the message and find out who your secret love is click on the link below.
secretvalentine.exe
Regards Your secret crush!

From this email we can identify the key characteristics of a malware email: (1) these emails appear to be from a friend or an acquaintance; (2) they may not reveal the identity of the sender; (3) They play on curiosity of the receiver; (4) They ask the receiver to download an attachment.

Video Version: Based on these characteristics we designed the physical narrative for the malware video. We had an older adult pose as the intended target. The attackers were two people pretending to deliver Valentine’s Day messages. In the first scenario the older adult would let them in the house. One of the attackers then bugs the older adult’s phone so that they can listen in on the older adult’s conversation. In the second scenario the older adults does not let them in the house thereby thwarting the attack. In the last segment, we again draw the parallel between the physical analogy and the online risk, as shown in Fig. 2.

Fig. 2. Just like the bug, malware once installed captures sends it to the attacker.

STUDY DESIGN
While several efforts have been made to design risk communication technologies for risk education, they are usually evaluated experimentally with college students. This research specifically targets older adults. Older adults tend to have a different understanding of technology than younger adults. In particular they tend to be more cautious about technology. Recall, in this study we address two research questions. First, what is the effect on comprehension when using videos as opposed to text? Second, what are the determinants of older adults perception of online risk, specifically for responding to phishing and malware emails?

Research in cognition suggests videos provide richer comprehension. Conversely, there is evidence to show that older adults may feel overwhelmed by the use multiple of media in videos (visual, audio, text). There is also the question of assessing whether the physical analogies are accessible to older adults and if they understand how a similar attack might play out online. Older adults in general may be technology averse. Thus, we need to ensure that the design of the videos should not make them unduly anxious about technology or online financial management. Our design and research goal is that the videos result in avoidance of threat by older adults. A key goal of our study design was to determine if the videos or text better enabled older adults to clearly identify risk avoidance strategies.

In addition to answering these questions we sought to discover the determinants of risk. What are the characteristics of threats that are perceived as most risky? There is little research that explains the underlying determinants of online risk perception of older adults. In particular we seek to understand why or when older adults might disclose their financial information online or download an attachment. We also seek a better understanding of their mental models of online financial risk. Such an understanding would allow us to identify and address the key determinants in new designs for risk communication of this most vulnerable population.

In the next section, we describe the canonical nine dimensional model that we incorporated in the survey to measure risk perception. Further, we detail the design of questions that evaluate comprehension.

Determinants of Risk Perception
Identifying why and to what extent online threats may or may not be perceived as risky is necessary to design effective risk communication. Research in risk perception online has, however, been limited. Garg et al. investigated the applicability of a canonical nine dimensional model of risk perception based on expressed preferences.

The nine dimensional model was introduced by Fischhoff et al. to study risk perception in the offline world. These nine dimensions were grounded in the psychometric paradigm and consisted of voluntariness, immediacy, knowledge to the exposed, knowledge to science, control, newness, common-dread, chronic-catastrophic, and severity. Garg et al.
found that not all the nine dimensions are equally relevant online. Specifically knowledge to the exposed, knowledge to science, newness, and common-dread were not found applicable. They proposed a five dimensional model consists of voluntariness, immediacy, control, chronic-catastrophic, and severity for online risks. These dimensions have been adapted for the current work as follows:

1. Voluntariness: To what extent does Mr. Cullen have a choice in being exposed to this risk? (1=Voluntary, 5=Involuntary)
2. Immediacy: Is the risk from the threat immediate or does it occur at a later time? (1=Immediate, 5=Delayed)
3. Control: To what extent can Mr. Cullen control (or mitigate) the risk? (1=Uncontrollable, 5=Controllable)
4. Chronic-catastrophic: Does this risk effect only Mr. Cullen or does it effect many people? (1=Mr. Cullen/Chronic, 5=Many People/Catastrophic)
5. Severity: In the worst possible outcome, how severe would the consequences be? (1=Not Severe, 5=Severe)

**Comprehension: Video vs. Text**

Research has shown that videos can lead to richer comprehension over text. We measure comprehension of the videos by participants as follows: (1) they should be able to identify the risk; (2) they should be able to identify the attack vector; (3) they should be able to identify the potential consequences of the risk; (4) they should be able to suggest strategies to avoid or mitigate the risk.

In our beta test of the study design, we asked the participants close ended multiple choice questions, e.g. ‘Why do you think the older adult was suspicious of the agent?’ This sometimes biased the participants. For example, a participant may not feel that the older adult was suspicious of the agent. Once the question is asked, however, the participant might nevertheless think of justifications. Thus for the pilot our questions were open ended. Participants were asked the following questions: (1) what is phishing?; (2) how does phishing work?; (3) how can you avoid phishing?; (4) list everyone that suffers if a phishing attack is successful; and (5) describe the impact of phishing on the people or organizations listed above. The findings and responses to these questions are discussed later in the results section.

**Procedure**

The participants were asked to watch part of the first segment of the video, to the point where the fake agent asks the older adults to divulge the information. Participants were then asked to identify which they considered more risky: responding or not responding. Further, they rated both the risk of responding and not responding on the five dimensions of risk perceptions described previously. The rating was based on a five point semantic scale.

The participants were then shown the remaining section of the video. The participants were then asked to answer the comprehension questions. The participants were asked to think of themselves as the older adult in the video and the risk to them as that older adult.

**RESULTS**

Some iterative beta testing was conducted with ten older adults for both the phishing video and the evaluation survey during the design phase. Many of the older adults had trouble hearing the audio. In the second iteration we added subtitles to the video. While this was counter to the guidelines proposed by Fisk et al., we found that in this particular case, older adults preferred having both the subtitles and the audio. Initially, the comprehension questions were close-ended and multiple choice. However, posttest interviews indicated that such an approach might prime the participants. Thus, the second iteration included only open-ended questions.

The following results were from the pilot studies with a convenience sample of older adults. The participants were randomly assigned to either the video or the text group. The pilot studies were conducted only for the phishing video. We had twelve participants in the pilot study. There were eight females and four males. Participants ranged in age from 70 through 85. Ninety-percent have adult children, with almost half having children living nearby. About 25% were married; the rest lived alone. All were mobile, healthy, and cognitively high functioning. Ninety-eight percent had attended college and six had graduate degrees. All were residents of a local, affluent retirement facility; most lived independently in cottage-style housing or apartments, but could take advantage of the central dining facilities and social activities.

A preliminary anonymous survey was administered to the group. Most participants were familiar with at least some form of information technology (computers, cell phones, etc.). A small minority used a medical alert bracelet or other personal safety-monitoring device; only a few had experience with any other monitoring or other home-based technologies. Six of the participants watched the videos and filled out the survey instrument based on the video. The other six read the textual description of the risks and filled out the survey instruments based on text. In the video group five of the participants were female and there was one male. In the text group there were three males and three females.
**Video based survey**

All six participants rated the risk of responding to be higher than that of not responding. The risk of responding consisted of: (1) IRS agent might use the information against the older adult; (2) The older adult did not have enough information to verify the authenticity of the IRS agent; (3) The older adult might become the victim of theft.

While the risk of responding was rated higher, not all items on the five dimensions are rated higher for responding. This indicates that not all dimensions have equal weights in the construction of perceived risk. While the sample size in this study is too small to allow statistical analysis to identify those weights, it does encourage further investigation.

The risks of not responding to the IRS agent were seen to be none at best and more visits from IRS at the worst. The characteristics of phishing were: (1) criminal act; (2) stealing private information or identity; and (3) impersonation of legitimate entities for financial gain. Participants had more difficulty explaining how they would identify phishing. Only two participants could make tangible proposals: companies would not ask for private information online and before providing information call the company and verify the requesting agent. Participants had an easier time explaining how to avoid phishing. Most participants recommended not giving out private or financial information online and not trusting emails. Participants identified themselves, their family, their bank, bank accounts, and businesses as entities that would suffer if they get phishing. Financial loss was the most frequently identified consequence of being phishing. Other outcomes were loss of privacy, trust, and decreased credit ratings.

<table>
<thead>
<tr>
<th>Responding</th>
<th>Yes</th>
<th>No</th>
<th>Rating Scale</th>
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<tbody>
<tr>
<td>Voluntariness</td>
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<td>3</td>
<td>1=Voluntary, 5=Involuntary</td>
</tr>
<tr>
<td>Immediacy</td>
<td>1.5</td>
<td>3.25</td>
<td>1=Immediate, 5=Delayed</td>
</tr>
<tr>
<td>Control</td>
<td>3</td>
<td>4</td>
<td>1=Uncontrollable, 5=Controllable</td>
</tr>
<tr>
<td>Chronic-catastrophic</td>
<td>3.75</td>
<td>3.25</td>
<td>1=Chronic, 5=Catastrophic</td>
</tr>
<tr>
<td>Severity</td>
<td>5</td>
<td>4.5</td>
<td>1=Not Severe, 5=Severe</td>
</tr>
</tbody>
</table>

Table 1. Average risk ratings for video group

**Text based survey**

All six participants rated the risk of responding higher than the risk of not responding. The risk of responding consisted of: (1) giving out too much information; (2) invasion of privacy.

None of the participants articulated the risk of not responding. Phishing was described as: (1) misleadingly or apparently legitimate, (2) email scam, and (3) procuring valuable personal or private information. Participants had more difficulty describing how they would identify phishing emails: (1) email can be identified as phishing based on the information requested, e.g. SSN; (2) strangers prying into private information; (3) sometimes it is difficult because it seems authentic, but no legitimate business would ask for personal information unsolicited; (4) the request includes information one should not share; (5) the proposal is often unrealistic and tries to offer a reward to the receiver for providing information or financial help that will hurt the receiver legally or financially.

<table>
<thead>
<tr>
<th>Responding</th>
<th>Yes</th>
<th>No</th>
<th>Rating Scale</th>
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<tr>
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<td>Immediacy</td>
<td>1.8</td>
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<td>1=Immediate, 5=Delayed</td>
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<td>Control</td>
<td>1.8</td>
<td>4</td>
<td>1=Uncontrollable, 5=Controllable</td>
</tr>
<tr>
<td>Chronic-catastrophic</td>
<td>3</td>
<td>2.75</td>
<td>1=Chronic, 5=Catastrophic</td>
</tr>
<tr>
<td>Severity</td>
<td>5</td>
<td>2.5</td>
<td>1=Not Severe, 5=Severe</td>
</tr>
</tbody>
</table>

Table 2. Average risk ratings for text group

**DISCUSSION**

Participants in the video group were more likely to articulate the risk of responding or not responding than the text group. In the video group four participants provided a textual description of the risk of responding and three participants described the risk of not responding. In comparison, for the text group, only two participants enumerated the risk of responding and none indicated a risk of not responding. The risks of responding were also more concretely defined by the video group participants. For example participants in the video group stated theft as a risk of responding, which is much more tangible than the abstract loss of privacy offered as a risk by the text group. This suggests that participants in the video group had better comprehension of the risk than the text group.

All the participants in both the groups rated the risk of responding to be higher than the risk of not responding. In the video group, participants rated the risk of responding to be more voluntary, more immediate, less controllable, more catastrophic and more severe, as compared to the risk of not responding. In the text group, the risk of responding was seen as
less voluntary, more immediate, less controllable, more catastrophic, and more severe. Thus clearly participants in the video group felt that the victim had a choice in responding or not responding. The text group felt that they could not avoid the risk of their own volition.

Both the groups provided similar definitions of phishing. Both the groups had more difficulty explaining how to identify phishing than they had defining phishing. While both the groups recommended not responding to such emails to avoid getting phished there were subtle differences. Participants in the video group talked about the issue of trust and how there is no inherent trust in emails. This is important as it indicates that participants in the video group under-stood the underlying principle of phishing and similar email based scams as opposed to those in the text group.

Video group participants associated the risk of phishing more with personal loss. Two participants in the text group did not list themselves as entities that would be impinged if phishing were successful. One of the participants listed family first and themselves second. The participants in the video group were seen to use phrases like my bank, my social security number etc. They also more accurately described the financial risks. Instead of listing a generic financial service that would be effected, they gave specific examples, e.g. bank account numbers that would be compromised.

**CONCLUSION AND FUTURE WORK**

In this paper we presented the design of narrative driven risk communication videos targeted towards older adults. These videos targeted online financial risks of phishing and malware. We presented the design of these videos and an evaluation strategy. The results are promising in terms of communicating the risks of phishing attacks. The results are illustrative rather than conclusive and do not claim to provide a quantitative assessment. A larger study is in progress due to this successful pilot.

Participants who watched the video saw themselves and their assets as being more at risk when compared to those who read the text. Video participants were also able to articulate both the description of the risk and the implications of responding vs. not-responding in more concrete terms than the text group. This indicates that videos might be better at explaining online risks to older adults despite previous work arguing the converse.

The contribution of this work is not in the use of videos for training purposes. Rather this work presents guidelines for the development of narrative-driven videos that leverage physical mental models for risk mitigation online targeted towards older adults. We build upon previous work by presenting risk not as is, but by abstracting it to mental models that are more accessible to non-experts. Finally, we evaluate our design with older adults who differ from younger adults in their cognitive capacity. This demographic has been under served by previous studies, which have primarily concentrated on younger adults.

**References**


Environmental Modeling for the Optimal Energy Control of Subway Stations

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Purpose Underground transportation systems are big energy consumers and have a significant impact on energy consumption at regional level. One third of the networks’ energy is required for operating the subsystems of metro stations and surroundings, such as ventilation, vertical transportation and lightning. Although a relatively small percentage of energy can be saved with optimal management of these subsystems, in absolute terms this means large energy savings are obtained. Furthermore, optimal management is a big opportunity for energy efficiency since it involves much smaller investments than those usually applied to transportation by providing new ways for sustainable energy saving solutions. In this perspective, the EU-funded R&D project SEAM4US (Sustainable Energy Management for Underground Stations) is aimed at defining a technological and methodological framework for optimized energy management in public underground spaces, which will be applied to the dynamic control of the energy consumption in Barcelona Passeig de Gracia subway station.

Method The development of a new class of predictive control logics, behaving consistently in changing environments is at the core of the optimal energy management approach and it is one of the main objectives of this research. This class of control systems is based on advanced environmental models, directly coupled with an environment monitoring sensor network, that is capable of interpreting the sensed data (both indoor and environmental) and of forecasting future states. In order to achieve the necessary level of robustness these models must be able to learn from previous states so they can adapt to the varying environment. The development of this class of environmental models for large underground environments like subway stations involves the elaboration and the integration of different simulation models concerning natural and forced ventilation, passenger movement, lighting systems, and their integration in a unique formal statistical framework, which is able to manage the uncertainty affecting the sensed data and to learn from the data flow. Results & Discussion We will outline the methodological approach to the development of the Passeig de Gracia environmental models for the optimal control of its energy consumption. The adopted hybrid modeling solutions, integrating different classes of simulation means in a unique Bayesian framework, and a preliminary architecture of the overall control system will be presented.

Keywords: information technology, management and social issues, realities or application systems, energy efficiency

INTRODUCTION

Control systems applied to public underground environments, like subway stations, have been traditionally based on suboptimal homeostatic short-term feed-back mechanisms which are applied singularly to each equipment type. Recently, the availability of pervasive sensor networks, allows us to accurately monitor dynamics of the indoor environment and to implement complex anticipatory optimal control policies. The implementation of optimal control policies requires the development of integrated models capable of predicting the near future behaviour of the controlled environment under specific conditions, so that the optimal solution can be sought through scenario analysis.

The objective of the SEAM4US research is the development of an advanced control system for the “Passeig de Gracia – Line 3” (PdG-L3) subway station in Barcelona capable of setting up the internal environments opportunistically, in the optimal way, on the basis of forecasts regarding the external environment, according to energy efficiency, comfort and regulation requirements. This application domain raises a number of issues which make the development of a station’s integrated model a challenging engineering task.

Application domain

First of all, the integration of dynamics and scales at different levels, both in time and space domain. In fact modelling environmental processes that are time-continuous (weather, building physics) and typical events of a subway station (train arrival, people activities) into a single framework is quite complex. Furthermore, the analysis of occurring environmental dynamics often requires dimensional scales moving from the decimetres of a fan vent to the thousands of meters of urban canyons.
Second, different processes characterizing subway station dynamics have different natures. Discrete time events, quite random processes such as passenger flows, multi-physics involving thermal, airflow and pollutants, stochastic processes such as the weather should need very different type of models. Their integration in a unique model requires the adoption of a rather articulated modelling approach, in order to study each process with the most effective computational tool available, and to subsequently use a very flexible modelling mechanism to integrate each single model in the overall framework.

These models must also be capable to integrate advanced control processes, in terms of sensor-actuator networks and control logics. This is far from usual, as common building simulation environments are mainly procedural and offer only quite basic control scenarios. Furthermore, most of the data defining models’ boundary conditions is affected by uncertainty to some degree. Therefore, the models should be capable of propagating this uncertainty throughout the computational chain, in order to support the decision maker with certainty factors qualifying the estimated performances.

A final noteworthy aspect concerns system adaptivity. As the model supports management decisions taken by the human controller, the proposed scenario must reflect changing reality as much as possible. To this objective, the models must be capable of improving their performance by adapting their behaviour on the basis of the measured environmental data.

CONTROL FRAMEWORK

Subway stations are nonlinear, multivariable non-stationary, stochastic and constrained processes even with hybrid dynamics (with mixed continuous, discrete, on-off variables). Despite the complexity of the process and interested domain, the control objective in the SEAM4US research is clear: minimize power consumption. Therefore, in order to maximize its efficiency, the control system needs to have some features.

First of all, the control policy has to be optimal, in the sense that it attempts to find the values of a vector of design parameters that yield optimal system performance, subject to some architectural and comfort constraints. The system performance can be measured by a so-called cost function.

The identification of control constraints is a challenging and key step: it could mean also considering a hierarchy of constraints and control functions. In fact, the economic operating point of a typical process unit often lies at the intersection of constraints, and often significant benefits do not come from simply reducing the variations of a controlled variable but dynamic controlling variable set-point to be moved closer to a constraint without violating it. Control constraints derive directly from implicit and explicit system/process requirements, such as comfort (thermal, lighting, acoustic…), health (e.g. air quality) and safety, but from the operational requirements of the equipment also. Furthermore, the control system has to be adaptive. In fact, even if most current techniques for designing control systems are based on a good understanding of the system under study and its environment, in cases like subway stations, the system to be controlled is too complex and the basic physical processes in it are not fully understood. Thus, control design techniques need to be augmented with an identification technique aimed at obtaining a progressively better understanding of the plant to be controlled. Adaptive control is a technique of applying some system identification technique to obtain a model of the process and its environment from input-output experiments and using this model to design a controller. The parameters of the controller are adjusted during the operation of the system as the amount of data available increases through on-line learning.

Finally, predictive control is necessary for achieving high energy efficiencies: prediction gives the capability of taking soft control actions in advance, thus, saving energy. Predictive control is based on the Receding Horizon strategy, that is the control action is designed by running the model of the process over a given prediction horizon and evaluating the control sequence that gives the minimum value of the cost function.

All these control features suit perfectly but require the development of integrated models capable of:

- achieving adaptation feature by recursive online identification (or tuning) of process model,
- fully exploiting stochastic models by including both predicted values and uncertainties in the cost function formulation, thus modulating the reactivity of the controller based on the reliability of the obtained predictions,
- predicting the near future behaviour of the controlled environment under specific conditions.

The SEAM4US approach adopts Dynamic Bayesian Networks (DBN) which provide native uncertainty management, machine learning capabilities and, consequently, offer a good basis for adaptivity and decision support.

MODELLING FRAMEWORK

In this perspective, a hybrid modelling framework was defined, aimed at integrating different types of models in an overall Bayesian model in order to efficiently support control logics. Operationally, different types of models are needed:
- a set of **predictive models** that can represent the stochastic variables such as weather. They also have been modelled through Bayesian Networks;
- the development of the overall DBN requires the definition of a training set and a number of fine tunings that can be accomplished only via a running model which closely resembles both the environmental physics and the control policies. It must be a **Whole Building model** and the SEAM4US approach develops it in the Modelica-Dymola simulation environment;
- various models are needed for the **detailed analysis and modelling of the thermal and airflow processes**. They are aimed at investigating a number of specific conditions that will be modelled coherently in the whole building model, through boundary conditions and specific components. They have been modelled through Finite Element Method (FEM) multi-physics models.

This section briefly presents the models developed so far and the structure of the preliminary Bayesian network that will support the controller. All models presented are a first version and need to be validated through experimental data in the following months.

**Weather Predictive Models**

The prediction of wind speed and direction are provided to both the airflow and temperature networks by the weather model. The weather model is a probabilistic Bayesian model, shaped as a fourth order Markov chain. Three chains representing air temperature, wind speed and direction were implemented as shown in Fig. 1.

![Fig.1. Weather Prediction Model](image)

The data provided by the Barcelona weather files were used to initially define the structure and the preliminary network conditional probability tables. The analysis led to a second order Markov chain for air temperature and wind speed and to a third order Markov chain for wind direction. Further refinements will be performed on the basis of the forecasting data provided by on-line weather services such as (WWO, 2012).

**Whole Building Models**

The Whole Building Model is fundamental in the overall model engineering process because it provides support to the development of the stochastic model through four main points:
- the definition of the pre-training set used to learn the conditional probability tables of the Bayesian Network;
- the integration of the devices’ operational constraints in the forecasting process;
- the definition of the optimal fading rate of the Bayesian Network learning algorithm which optimizes the adaptive behaviour;
- the overall assessment of the stochastic system before its deployment.

Although, as already said, it cannot be developed efficiently in the common building simulation environments, as they do not support features such as advanced control integration, multi-physics in many cases and the integration of specific components and/or boundary conditions. Specifically, for modelling the “Passeig de Gracia (PdG) - Line 3” it is necessary to insert specific boundary conditions for modelling the terminal sections of tunnels and corridors linking to other stations (station link in Fig. 2). At these boundaries, specific conditions in terms of Heat Flow, air flow and Mass Transfer (water and pollutants) have to be assigned in order to model the actual dynamics occurring.

![Fig.2. Overview of the three Passeig de Gracia stations, belonging to Line 2, Line 3 and Line 4.](image)

As common simulation software do not provide these key representational features, the Modelica framework, with the Buildings library in the current release and the Dymola® environment were chosen as the SEAM4US development platform.

In the current development state, the implemented physics are heat transfer and airflow. Lighting, passenger flow and trains will be implemented in future releases. The Modelica station model (Fig. 3) was built using the room model of the Buildings library customized for underground spaces (e.g. windows.
have been deleted) to reduce the number of variables and improve efficiency, making the large station model manageable.

A number of further customizations were required in order to match the particular equipment present in the station (i.e. fan coils models, lighting models, etc.) and, most importantly, to link their behaviour with actual energy consumption.

The data derived from the CFD scenarios were used for modelling the airflow in a number of pilot station boundaries such as lengthy pedestrian corridors leading to other stations (station link) and station entrances. In particular, Wind Pressure Coefficients for each entrance, were specifically computed for our case since, literature\textsuperscript{16} provides values and formulas for calculating the wind factor for low rise buildings which cannot be applied in this case.

An in situ survey is, of course, required in order to validate data obtained from CFD models. However, this approach allows estimating the overall thermal-fluid dynamics occurring in the pilot station before the deployment of the sensor network.

**Boundary and Specific Conditions through FEM Models**

The PdG whole building model contains a number of specific boundary conditions and specific spatial components that were modelled using data derived from FEM models. All FEM models developed represent airflows, using Computational Fluid Dynamics (CFD) methods and some of them combine it with heat transfer and transport of diluted species.

Literature concerning underground environments CFD FEM modelling is not much extended. Many studies are design-oriented, evaluating the effects of specific technological solutions\textsuperscript{17} or focused on modelling dynamics occurring in case of fire\textsuperscript{18}. Other studies are more oriented on discussing a methodology for an effective CFD modelling of subway stations. As usually, they are large volume, some simplifications have to be adopted. Yuan\textsuperscript{19} reports that simplification of the airflow to steady process and presumption of the transient velocity to the time-averaged velocity are applicable to simulate the distribution of temperature and air velocity of subway platform in the pulling-in cycle.

Two types of FEM models were developed so far.

**CFD models for Wind Pressure Coefficients**

Whole Building Models use Wind Pressure Coefficients for Computing airflows entering in the building (Fig. 5). An outdoor urban canyon model, encompassing the eight city blocks surrounding the station entrances, was developed to determine the pressure and velocity maps at the station entrances for each main wind reported in the Barcelona weather file. The model contains both the outdoor blocks and the underground environments (Fig. 4).

![Fig.3. The top level blocks of the “Passeig De Gracia” subway station Modelica model. Each top level block corresponds either to a main ambient or to a connection.](image)

![Fig.4. Typical streamline map resulting from an urban canyon simulation of the city blocks](image)
Critical parameters, like dimensions of the computational domain, have been determined on the basis of the literature. In any case, sensitivity analysis was carried out concerning the presence of tall trees, balconies and recesses in the building facades in order to determine the right detail level in terms of the geometric model. The simulation was carried out with COMSOL Multi-physics 4.2, 3D steady state analysis, with a mesh size ranging from 2.5m to 16.7m. In the end, 81 scenarios, distinguished for wind direction and speed at 200m altitude, were defined.

**FEM models for Specific Spaces**

A number of detailed FEM model for evaluating the airflow-thermal behaviour of specific spaces are needed, for instance for coherently modelling alternative corridor-spaces that in the nodal perspective of whole building software could be equivalent, but are not, in fact, because of their spatial features (Fig. 6).

In order to have more detailed airflow boundary conditions for the specific space models, a further set of 81 scenarios for a more detailed analysis of the overall indoor environment, with a mesh ranging from 0.35m to 3.26m was developed. This more detailed indoor analysis also integrated the boundary conditions imposed on the ventilation shafts by the two fan coils pumping air inside the station at a speed of 60000m3/h and the ones imposed by the tunnel fan coils extracting air at a speed of 90000m3/h.

The development of the specific spatial portion models is on-going. They combine heat transfer, CFD and transport of diluted spaces.

**Passeig de Gracia-Line 3 Bayesian Model**

The last model engineering stage consisted in the development of the PdG-L3 station’s Dynamic Bayesian Network model. The development of the Dynamic Bayesian Network, consists in three phases:

1. definition of the network topology; both static and dynamic (usually called structural learning),
2. preparation of the training set and the learning of the conditional probability tables,
3. final assessment of the network using the LPM as the reference before deployment, in a model-in-the-loop architecture.

The sampling time chosen was 30 minutes because of actual fan coils control time constant, which is about one hour. The training set for the network was obtained by running the Whole Building Model for one week. Assuming 30min sampling intervals, in this preliminary release, airflow dynamics was considered nearly instantaneous, since any pressure impulse from the outside is capable of propagating inside and is exhausted within one sampling interval. Hence, a simple static Bayesian Network was used to represent airflow (Fig. 7). The static network topology was directly derived from the station layout, and it completely reflects the sensor network topology. In other words, each DBN node corresponds to a sensor and the links reflect the physical connection among the indoor spaces. Three further nodes were added representing environmental conditions: outdoor air temperature, wind speed and wind direction (white nodes). The links between the indoor air temperature in each hall and the correspondent airflow capture the buoyancy phenomenon, while the links among the connections and the halls reflects airflow induced by the dynamic pressure gradients.

The yellow node (PL3_NET) accounts for the net flow passing through the platform and it was used for control strategies. Grey nodes refer to forced ventilation directly on the platform (Pl3_F) and from the tunnels (TL3_F). In order to estimate air temperature inside the station, given that the station envelope time constants exceed six hours, the envelope’s past thermal states must be taken into account (orange nodes in Fig. 7(b)). Figure 8 shows the Bayesian Network for estimating indoor air temperature in the station halls and in the platform. The network has been shaped and has been learned from a training set produced by the LPM.
**CONTROL STRATEGY**

From the controller point of view, PdG-L3 is represented as a block with inputs and outputs (Fig. 9). Inputs ( ) to the system are the variables that can be manipulated: Fans (frequency), Lights (level) and Signalling (for Passenger Paths). The outputs ( ) are the Power consumption and indicators for Comfort and Health States that must be controlled in order to reach certain reference levels ( ). The relation between inputs and outputs is also significantly affected by a set of disturbances ( ), such as weather, train arrival, passenger flows and fans external to the station: they cannot be manipulated but only “accounted for” by using direct measures, when possible, together with a Disturbance Model. The internal state dynamics ( ) is function of the actual state ( ), inputs, disturbances and time ( ), thus it is a non-stationary system.

The PdG-L3 Bayesian Model, that also include a state estimator, is used as model for guiding the predictive controller. The Disturbance Model is composed by different types of models (e.g. schedules for trains, predictive model for weather), and so far, some of them are still under development by other research groups, such as the users/passengers model. By connecting these continuous-time models to a discrete-time controller which samples the signals, the preliminary architecture of the SEAM4US control system can be represented at each time step as in Figure 10.

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**Fig.7. Airflow Static Network (a) the Bayesian Network structure mapped on the station model,(b) the network portion related to the platform**

The temperature nodes chosen for estimation (e.g. HN1_T4, HN2_T4, HN3_T4, PL3_T4) depend on the corresponding temperatures measured during the previous four hours (i.e. HN1_T4 depends on HN1_T0, HN1_T1, HN1_T2, HN1_T3) and from the outside temperature wind speed and direction, WT, WS, WD respectively.

**Fig.8. Indoor Temperature Dynamic Network**

This network is capable of predicting temperature with an average error of 0.3 and a standard deviation of 0.32, by selecting the expected value of the platform output distribution.

These networks will be integrated into other networks modelling other physics and events of the Passeig de Gracia station.

**Fig.9. Block diagram representation of PdG-L3 station.**

**Fig.10. Architecture of the model based adaptive predictive control system.**
At each control step, the state estimator internal to the PdG-L3 Model receives data about the given input () and measured output () (through the sensory system) from PdG-L3 station and computes an estimate for each significant state variable ( ). The PdG-L3 Model uses them, together with measured values, candidate input sequence ( ) coming from the Predictive Controller and predicted future disturbances ( ) obtained from the Disturbance Model for computing the predicted output sequence () and gives it back to the Predictive Controller. The optimal control policy ( ) is the sequence that minimizes a given performance index subject to a set of given operative constraints. Once the optimization problem has been solved, the first element of the optimal sequence ( ) is applied as control action. The overall procedure is repeated at each step thus closing the control loop.

**CONCLUSIONS**

This paper reports the modelling methodology and control architecture being developed for the optimal energy control of the “Passeig de Gracia – Line 3” subway station in Barcelona, in the ambit of the EU funded SEAM4US project. The paper outlines the main issues faced during the modelling of the extremely complex environment, and shows how large scale civil engineering applications involve a number of stringent requirements that cannot be satisfied if not with a complex model engineering approach. The paper gives an overview of the hybrid modelling solution involving probabilistic Bayesian modelling in conjunction with FEM CFD and Whole Building and their role in the overall modelling process and in the control framework. The project’s current development stage leaves a number of issues open, such as passenger flow modelling and integration and assessment after deployment on the basis of measured data.

**ACKNOWLEDGMENTS**

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**References**


Change and contract management modules of intelligent-program management information systems (i-PgMIS) for urban renewal projects

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Purpose
In recent times, urban renewal (UR) projects actively try to improve residential environments and recover functions of an urban infrastructure. These projects move forward simultaneously as multiple projects, rather than as one single project. To cope with this, program management techniques and a comprehensive management system which is based on these techniques are required. For this purpose the research team has developed an intelligent program management information system, i-PgMIS, that can efficiently manage and support urban renewal projects during the entire life cycle.

Method
The system provides cost management, duration management, risk management, performance management, green VE/LCC (Value Engineering/Life Cycle Cost), change management, contract management, an e-manual, and conflict management for UR-projects. This paper details the research that focuses on the change management and the contract management modules. Motawa et al. proposed a change management system for construction projects at project level by using the dynamic planning system based on fuzzy logic, and Zhao et al. proposed a prediction change management system for each activity at the construction phase by using the dependency structure matrix (DSM). In this study, change factors that commonly occur in UR-projects were first deducted by using the analytic network process (ANP), and the possibility of the change was estimated by using a Likert-scale. There is no specific method in the contract management module. The module focuses on how to manage contractors’ information, the collection of the contract documents, execution of the costs referred to in the contract documents, and so forth.

Results & Discussion
Since many changes take place and multiple contracts are signed during the progress of a mixed-use development project such as urban renewal projects, efficient management is essential to handle these projects successfully. It is expected that the project manager is able to efficiently manage contract duties and respond to a number of changes such as cost overrun and schedule delay during the project through the change management and contract management modules, as developed in this paper.

Keywords: change management, contract management, i-PgMIS, urban renewal

INTRODUCTION
Urban renewal (UR) projects have been actively implemented worldwide in recent years to promote improvement of the residential environment and functional recovery of underdeveloped cities. Since UR projects require large-scale project cost, long-term project duration and simultaneous progress for multiple projects, there have been limitations in the management of UR projects using existing project management approaches. To this end, the world’s leading construction companies have conducted many investment activities and researches to apply IT technologies in construction projects, thereby developing the Project Management Information System (PMIS) with technologies providing a substantial level. In Korea, with the introduction of construction management, the need to standardize construction information has been raised. Construction PMIS has been expanded as one of the essential tools for the success of projects. However, since PMIS is mainly used in the construction phase for a single project, its application to urban renewal projects is limited in terms of simultaneous implementation of multiple projects.

In this regard, our research team developed the intelligent-Program Management Information System (i-PgMIS). i-PgMIS is a web-based system that integrates unit modules of cost/duration management, risk management, performance management, Green VE/LCC, change management, contract management, E-Manual, and conflict management. This study is focused on the development of change management and contract management modules among the various modules described above.

LITERATURE REVIEW

Change & Contract Management System
In this study, the existing major researches on change management were first reviewed. Oh (2002) suggested a change management system for progress control, which considers progress delays caused by change order. Charoenngam et. al.
(2003) developed a management system for change order that supports integration, communication and documentation practices transpiring among a variety of subject participants. Motawa et.al. (2007) developed a system to assess the impact and predict changes using fuzzy logic and Dynamic Planning and control Methodology (DPM). Zhen et.al. (2010) developed a system to predict changes by establishing the standards by re-work of the construction phase based on the Dependancy Structure Matrix (DSM), and analyzed the probability of change on the predicted changes by using the Monte Carlo Simulation (MCS).

Existing studies on change management mainly focused on prediction changes and evaluation the degree of impacts. Most of them were developed in the form of individual systems and there was no research presenting the supporting of the construction management by connection with other systems.

The main contents of the previous studies on contract management include checklist development and management plans, and some of the modules of Enterprise Resources Planning (ERP) conducted the contract management.

Existing studies on contract management mainly dealt with the efficiency of management and claims prevention rather than system development. In addition, since EPR has been widely applied to finance and accounting for corporate management, it has its limitations when applied in construction project management.

The abovementioned studies are summarized in Table 1.

Table 1. Literature Review

<table>
<thead>
<tr>
<th>Category</th>
<th>Author</th>
<th>Substance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Motawa et. al. (2007)</td>
<td>Development of change prediction and change effect evaluation system using the DPM and the Fuzzy Logic</td>
</tr>
<tr>
<td></td>
<td>Zhen et.al. (2010)</td>
<td>Development of change mgmt. system using the DSM for construction phase</td>
</tr>
<tr>
<td></td>
<td>Lee et. al. (2009)</td>
<td>International construction contracts with FIDIC suggests to promote adminstrative efficiency.</td>
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</table>

Functions of i-PgMIS

In this study, the analysis of the major technologies for program management was carried out for efficient management of UR Projects. The P(g)MIS such as e-Build, PMweb, MOCA, and Proliance developed mainly been used to manage programs or projects in the US, was particularly analyzed. Fig. 1 shows a summary of the major functions included in the i-PgMIS and systems mentioned earlier.

As identified in Fig. 1, asset management, facility management and energy management were not included in the functions of i-PgMIS. On the other hand, performance management, conflict management and green VE/LCC were included as additional functions. The functions included in i-PgMIS were finally determined in consideration of the expert’s opinions and characteristics and budget of this research project.

Fig. 1. Comparative Table of Major P(g)MIS & i-PgMIS

DEVELOPMENT OF CHANGE MANAGEMENT MODULE

Evaluation Criteria for Change Factors

Due to various change factors such as contracts, methods, regulations and business environment, large-scale programs such as UR Projects have a huge effect on the overall business. This impact of the change factors may leads to a project delay, cost overrun, and reducing feasibility.

Accordingly, in this study the evaluation criteria for the change factors affecting the business were deduced before the development of change management modules. First, expert interviews were conducted to deduce the evaluation criteria suitable for the UR projects based on the nine change factors presented in the Project Management Body of Knowledge (PMBoK), and the results were delivered through integration or addition/deletion by reflecting the similarities between factors as shown in Table 2. ‘Risk management’ was deleted since its’ contents are applicable to all parts.

Table 2: Evaluation Criteria for Change Factors

<table>
<thead>
<tr>
<th>Change Factors</th>
<th>Evaluation Criteria</th>
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<tr>
<td>Contracts</td>
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<tr>
<td>Methods</td>
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<tr>
<td>Regulations</td>
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<tr>
<td>Business</td>
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<td>Environment</td>
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<td>Projects</td>
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<tr>
<td>PMBoK</td>
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<tr>
<td>Integration</td>
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<tr>
<td>Addition/Deletion</td>
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<td>Similarities</td>
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206
Table 2. Evaluation Criteria from PMBoK

<table>
<thead>
<tr>
<th>No.</th>
<th>Change Factors of PMBoK</th>
<th>Evaluation Criteria</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1</td>
<td>Integration Mgmt.</td>
<td>Projects plan</td>
<td>Integration</td>
</tr>
<tr>
<td>2</td>
<td>Scope Mgmt.</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Procure Mgmt.</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>Time Mgmt.</td>
<td>Projects Schedule</td>
<td>Remain</td>
</tr>
<tr>
<td>5</td>
<td>Cost Mgmt.</td>
<td>Projects Cost</td>
<td>Remain</td>
</tr>
<tr>
<td>6</td>
<td>Quality Mgmt.</td>
<td>Quality/ Safety</td>
<td>Add.</td>
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<tr>
<td>7</td>
<td>Human Resource Mgmt.</td>
<td>Stakeholder</td>
<td>Integration</td>
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<tr>
<td>8</td>
<td>Communications Mgmt.</td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>Risk Mgmt.</td>
<td>All parts</td>
<td>Delete</td>
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Since the range of specific changes are too wide for the five evaluation criteria, the detailed evaluation items of the five evaluation criteria were deduced through a questionnaire survey on 3 UR projects currently implemented in Korea, targeting 11 personnel in charge of UR projects. From its result, 64 detailed evaluation criteria were additionally deduced. Among them, the same and similar items were integrated to finalize a set of 22 evaluation criteria. Table 3 shows the summarized results.

Table 3. Deduction of Evaluation Criteria for Change Factors

<table>
<thead>
<tr>
<th>No.</th>
<th>Evaluation Criteria</th>
<th>No.</th>
<th>Sub-criteria</th>
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<tbody>
<tr>
<td>1</td>
<td>Projects plan</td>
<td>1</td>
<td>Difficulty in financing</td>
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<tr>
<td>2</td>
<td></td>
<td>2</td>
<td>Concerned about design error</td>
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<tr>
<td>3</td>
<td></td>
<td>3</td>
<td>Project cancelation due to profitability</td>
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<tr>
<td>4</td>
<td></td>
<td>4</td>
<td>Issues regarding surrounding infrastructure</td>
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<tr>
<td>5</td>
<td></td>
<td>5</td>
<td>Insufficient business planning due to equity problem</td>
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<td>Delay in construction completion</td>
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<td>Projects Schedule</td>
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<td>Delay in existing building disposition</td>
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<td>Delay in trial run</td>
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<td>Difficulty in material supply</td>
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<td>Additional construction cost</td>
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<td>Poor construction work</td>
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<td>Additional construction cost</td>
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<td>16</td>
<td>Quality/ Environment/ Safety</td>
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<td>Safety accident</td>
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<td>17</td>
<td>Deterioration in quality</td>
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<td>Civil complain</td>
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<td>22</td>
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<td>22</td>
<td>Conflict between participants</td>
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Development of Change Management Process

In case of changes in specific activities within the business process, it is very important to determine how much impact the changes has on the overall business and other activities and what measures should be taken.

To support this, a process for change management was developed in this study. The change management process is divided into four stages: Identification → Evaluation → Approval → Notice. The contents are schematized in Fig. 2.

Identification

In the Identification stage, changes are perceived and requested. In this stage, a change requestor designates a reviewer and an approver, wherein the change reviewer can be a manager in charge of main categories of Table 3, and the change approver can be a general project manager or an owner. In this stage, the change requestor should attach relevant documents or papers to help the change reviewer or approver in the next processes.

Evaluation and Approval

These two stages contain a significant amount of information as the most important stage in the change management process. In particular, accurate assessment of changes can be conducted by making the change reviewer and approver independent of each other.

Once review requests on changes are received from the identification stage, change manager(s) conduct the assessment based on the evaluation criteria.
(sub-criteria of Table 3) using the 5-point Likert scale. When assessment is completed, the evaluation scores are calculated automatically, and then approval on changes is requested along with the evaluation results. However, the progress is return to the first stage if half of the reviewers reject the changes. Next, approval on changes is received, where the change approvers give a final approval after validation. However, they can reject the request for approval or ask the change reviewer to review the evaluation results if they are deemed inadequate. All the information generated in the earlier processes is stored in the change D/B.

Notification
The notification is the final stage in the change management process. As mentioned above, since the changes in specific activities affect other activities, managers in charge should recognize the approved changes and undertake follow-up measures. However, since the follow-up measures vary depending on the changes, it is difficult to present concrete countermeasures through this study. Accordingly, notification comes in the final stage of the change management process.

User Interfaces (UIs) for Change Management Module
As mentioned earlier, the change management module was developed into 4 steps and the main UIs are as follows:
1) "Change Requirement UI" - requests for review on the changes based on related information after perceiving changes
2) "Change Evaluation UI" - evaluates changes
3) "Change Approval UI" - approves the final evaluation results
4) "Change Result UI" - identifies the approved change results

Change Requirement
Initial changes are perceived offline, and when change is needed, the relevant information is collected. Based on the information, reviewers approve changes after the review process. The change requirement UI for receiving approval is shown in Fig. 3.

First, the information regarding changes such as change title, change code, request date, requestor, matter of urgency, change factors, keywords and the details of the requested change are registered (see of Fig. 3). Next, a change requestor designates the reviewers and approver who can review and approve the requested changes (see of Fig. 3). In of Fig. 3, additional files can be registered by clicking 'attachments', and change request is completed by clicking 'review request'.

Change Evaluation
The UI for change evaluation was developed based on evaluation criteria as shown in Fig. 4.

In case of change review, the relevant information can be identified by reviewers specified in the Change Requirement. First, the basic information registered at the Change Requirement stage is presented in of Fig. 4. In of Fig. 4, evaluation is carried out based on the evaluation criteria deduced earlier by means of the 5-point Likert scale. After the evaluation is completed, approval is requested by clicking 'review completion' in of Fig. 4. If evaluation scores are low or there is missing information, the change request is rejected and the process is returned to the identification step. Even if the changes were rejected, the information regarding the changes is stored in Change D/B for change history management.
Change Approval
In this stage, the final decision is made by identifying all the requested information after the completion of review. The UI is shown in Fig. 5.

Fig. 5. Change Approval

First, the change approver identify the information on the change requests (see of Fig. 5) registered in the change requirement stage and evaluation results by the change reviewers (see of Fig. 5) in the change review stage. More comments by reviewers can be seen by clicking ‘details information’ in of Fig. 5.

Approvers create a written approval (see of Fig. 5) by referring to the above contents, and subsequently give a final approval by clicking ‘change approval’ in of Fig. 5 after completing the review. A ‘review’ can be requested to the change reviewers or the “reject” can be accepted if the contents are insufficient, it’s depending on the results of the review. All the related information is stored in change D/B.

Change Result
In change Result UI, the approved changes can be identified on a list. Fig. 6 shows the details of the screen.

Fig. 6. Change Result

In of Fig. 6, each approved change can be searched through keywords, title, and requestors, and the detailed information regarding the changes can be identified in of Fig. 6.

The notification was suggested in Fig. 2. The approved changes with a final approval are notified to each manager (Cost, Duration Managers, and etc.), who revises information on the approved changes after receiving the notice.

DEVELOPMENT OF CONTRACT MANAGEMENT MODULE

Deduction of Contract Management factors
In the process of implementing large-scale programs such as urban renewal projects, many participants perform tasks by entering into agreements. Details included in the contract documents can vary in accordance with type of the contract, but items such as contract amount, contract date and contracting parties are included in all contract documents.

In this study, to deduce required items included in contract management, the PMIS for management of a single project was analyzed, and based on the analyzed results, interviews with professionals in charge of the contract business were carried out. The results are summarized in Table 4.

Table 4. General Information for Contract Management

<table>
<thead>
<tr>
<th>Category</th>
<th>General information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential</td>
<td>Contract name, type, method, date, start day, end day and so on</td>
</tr>
<tr>
<td>Detail information</td>
<td>Depending on the type of contracts.</td>
</tr>
<tr>
<td>Continuous action.</td>
<td>Mgmt. of contract history, Mgmt. of execution history.</td>
</tr>
</tbody>
</table>

Development of Contract Management Process
As a contract regarding the contractor cost can be changed due to change orders, a contract can be changed depending on the project's characteristics during the construction process. In this study, a process for contract management was developed based on the contract information deduced earlier, which is schematized in Fig. 7.

The contract management process of Fig. 7 is explained as follows: first, if a contract for the project is conducted, required items (refer to Table 5) are entered into the system, thereby registering the contract information. If the business is conducted in accordance with the terms of the contract, progress payment is executed according to the contract documents, and the contract is terminated. However, in case contract changes are requested, relevant information is required, and the contract information is reregistered when the executed progress payment is continuously accumulated. It must be managed until the total contract price is executed.
UIs of Contract Management Module

In this study, a contract management module was developed based on the contents deduced earlier. The UIs included in the contract management module are divided into the following categories: "contract information registration UI," which registers required contract information in case of making a contract; "contract history management UI" and "execution history management UI" for continuous management of the contract contents in the process of implanting the projects. In addition, "contract status UI" which identifies lists of the entire contracts; and "contractor management UI" which manages the detailed information of contractors are also included in the contract management module. Among the various UIs mentioned above, the "registration of contract information", "management of contract history" and "management of established history" are dealt with in this study.

Registration of Contract Information

Once a contract is made, the contract information is entered into the system for contract management. In this study, to manage the required information related to the contract summarized in Table 5, a UI was developed as shown in Fig. 8.

First, click on 'Add' button (see of Fig. 8), the screen for entering the details (refer to Table 5) of the new contract is provided in of Fig. After entering the contract information, the contract manager stores the inputted details by clicking ‘Store’ button (see of Fig. 8), then the contract is added into the contract lists of of Fig. 8.

Whenever new contracts are made, the abovementioned process is repeated, and all contracts signed are recorded in the contract list of in Fig. 8 upon project completion.

Management of Contract History

Due to project specifications and circumstances, contract changes can be made at a certain point, which will require changes in the contract amount and date of progress payment. To deal with these changes, a function of contract history management was constructed in this study. Fig. 9 shows the UI for management of contract history.

First, one of the contracts for which contract changes are made is selected in contract list of in Fig. 9 (the same as of Fig. 8). Next, information on the changed contents of the contract is entered in of Fig. 9 by clicking the ‘Add changed contract’ button of in Fig. 9, and then it is stored by clicking the ‘Store’ button of in Fig. 9. The changed information on the contract history is managed through linkage with information in Fig. 8.
Management of Execution History
In general, if it is a long-term project, the total contract cost is paid based on the order of payment division. In the case of construction work, progress payment is executed according to the earned value, and for design for CM contracts, the total cost is paid by monthly or quarterly installments. In this study, execution history management UI was developed for the management of the amount paid as time progresses, and is shown in Fig. 10.

Fig. 10. Mgmt. of Execution History

First, one of the contracts is selected from the contract list of in Fig. 10 (the same as of Fig. 9). Next, the amount of execution and execution date of corresponding orders is entered in of Fig. 10 by clicking the ‘Add’ button of in Fig. 10. The execution results are then stored by clicking the ‘Store’ button of in Fig. 10. Through the above process, the execution results of all contracts are registered for continuous management.

CONCLUSION
To promote improvement of the residential environment and functional recovery of underdeveloped cities, urban renewal projects have been actively implemented worldwide in recent years. However, since UR projects require simultaneous progress of multiple projects, there have been limitations in the management of UR projects using existing business management approaches. Therefore, the program based technologies are required. To support this, our research team developed the i-PgMIS which integrates several unit modules such as cost/duration management, risk management, performance management, green VE/LCC, change management, contract management, E-Manual and conflict management. This study dealt mainly with the development process of change management and contract management modules.

To develop change management modules, the evaluation criteria of change factors were first deducted and the change management process was developed. And then, the UIs for change management were developed. Likewise, in the development of contract management modules, contract management factors were deducted first, followed by UIs for contract management developed based on the development of the contract management process. It is expected that the change management modules developed in this study could support decision-making regarding changes through quantitative evaluation of the changes that occurred during project implementation. In addition, the contract managers are expected to comfortably and easily manage the history of progress payment and changes in the contract that occurred during project implementation using contract management module.

ACKNOWLEDGEMENT
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References
Refurbishing homes for elderly using BIM and CNC technology

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Purpose This article was developed in the context of research on a construction system based on CAD-CAM-BIM and CNC (Computer Numerically Controlled) technology and it is focused on the implementation of sustainable refurbishments in historic districts. During field work in historic districts, it was established that more than 25% of the population in these areas is older than 60, and most of them have lived in the same apartment or house their whole life. The problem is that these old timberframed buildings require better equipment to fit elderly peoples’ characteristics. For instance, a better distribution of space in the home would be beneficial to the elderly. To ensure better living conditions for the aging society, comfortable and big bathrooms, corridors, and doors are necessary, instead of the narrow and cramped current spaces. Likewise, more space for the installation of technological equipment is needed to support people who are disabled. Automated homes for the elderly require machinery that take up a significant amount of space. Moreover the installation of new equipment and redistribution of space has to be done rapidly so that the process creates minimum disturbance. The construction system that is being developed gives priority to the preservation of the current timber-framed structure and masonry walls, instead of dismantling the inner structure. This way, the refurbishment works are less traumatizing and the elderly and their elderly neighbors can continue to live in their homes.

Method The construction system is designed for different building contexts to demonstrate its universal applicability. Before being applied in a real situation, the first step was to ensure the refurbishment system’s suitability using virtual tools. For this purpose, a BIM-building simulator was used. The preliminary works focused on two different building typologies. The first typology is an apartment building (located in Bilbao) with a common staircase where properties are divided horizontally. The second typology is a terraced house located in London. In both cases, the refurbishment system was compared to traditional refurbishment processes. The parameters of comparison have been refurbishment costs, timing, and quantity of used energy. In both cases the project was personalized for a disabled aged person.

Results & Discussion A proper refurbishment process grounded on CAD-CAM-BIM and CNC-technology needs to be based on detailed and exact measurements. Moreover, it is advisable to collect data more than once during the refurbishment process because the timberframed building could move some millimeters. To avoid problems due to measurement errors, the CNC-fabricated pieces should offer measurement tolerances in order to facilitate the assembly and staging process. These first steps of the project – the defining of the refurbishment system – take a long time, since all the joints must be designed in 3D. This delay in the design process will be reduced when a detailed BIM-library is set up. However, the duration of the building site process is clearly shortened and that is why how disturbance is minimized. The construction system enables a flexibility of the inner distribution and the BIMsoftware helps with the tracking or monitoring of changes in the future. If the health condition of the elderly person requires more care or supply, modifications in the home can be fixed easily.

Keywords: refurbishment, CAD-BIM-CNC technology

INTRODUCTION Many buildings formed by load-bearing walls and inner wooden joists have become useless for some inhabitants and particularly for the aged people. The increasing aged society needs to refurbish or renovate homes, especially in the buildings with timber joists. During the field work made in the historic districts, it has been certified that more than 25% of the population in this areas is older than 60 years 1. Those buildings need a customized refurbishment owing to the countless variety of geometries 2. Using BIM (Building Information Modelling) and CNC (Computer Numerical Control) technologies could be useful to improve the nowadays refurbishment process situation.

Due to last advances in Software eta CNC fabrication, it is possible nowadays to fabricate building elements with complex geometry 3. This availability to produce elements with complex geometry can be useful in the field of old building refurbishment. Similarly, last advances in accurate measurement and 3D data collection can be profitable 4, 5, 6 in order to get a more accurate data collection.

The background research’s overall main purpose is the implementation of automation and “robotization” in the refurbishment processes of buildings. The research contemplates a definition of a “Refurbishment System” that could be used in the future refurbishment of buildings. This paper is a reflection about the comparison between the ongoing research and the traditional refurbishment processes. Particu-
Terraced Houses, where independent houses are
organized in a row. This typology was preferably built
in the cities of Anglo-Saxon countries.

The approach to refurbish is different in each typol-
yogy. In the block, the minimum habitation unit is the
flat whereas, in the Terraced House, the home unit
includes several floors, from the basement to the
roof. The problems and the solutions are different.

In both cases, many buildings have become out of
phase and they need a refurbishment. Sometimes,
the lack of a proper maintenance provoked several
pathologies in several building elements. Some other
times, the inner distribution became inefficient for the
inhabitant. In these cases a readjustment is needed
to adequate to the new situation. This paper empha-
sises the refurbishment works for the proper fitting of
minimum home units for the aged people.

RESEARCH METHOD
As it has been said before, the building context is
different from one country to another. And the re-
search itself has to be developed in different ways.
The proportion of buildings made using the load-
bearing walls and inner wooden joists is low in Bil-
bao. This is mainly because the biggest urban explo-
sion was made during 1960 decade. During this
period, reinforced concrete technique was the most
extended technique. Although there is quite an im-
portant research dealing with the pathologies with
this kind of buildings, grounded on the nearby city of
Donostia, literature about refurbishment of old tim-
ber buildings is not particularly big in the Basque
Country. In order to find facts, samples of refurbish-
ment have been monitored in the old quarter of Bil-
bao. Altogether, ten apartments have been moni-
tored. All of them were located in different blocks and
their owners were private investors. In four cases,
the apartment was the main home of the owner.

Eight of them were close to 70 square metres while
two of them were around 120 square metres. One of
these 120 sq m apartments was divided in two
apartments.

The monitoring started in each case with the first
contact with the client and finished when the refur-
bishment works were over. The parameters of the
monitoring are as follows:
1.- Possibility to obtain a proper home for an aged
person.
2.- Period length of the project and the works in the
building site.
3.- Collateral damages caused in the neighbour-
hood.
4.- Size or amount of work in each case.

The data collected in those monitoring have been
compared with a different building context, that is,
the Terraced Houses in the UK.

The proportion of buildings made using the load-
bearing walls and inner wooden joists is bigger in the
United Kingdom than in the rest of Europe. During
the Victorian period, and particularly in the 1.890
decade, more than 150.000 terraced houses were
built in the UK. Most of them are still up nowadays,
there are close to five million homes just in England.

Facts and data about refurbishment of this kind of
buildings are already collected. Literature about this
topic is wide, and it has been used for the compari-
sions.

In all cases, the possibilities and needs to implement
a refurbishment using BIM and CNC technologies
have been analyzed.

Towards a definition of the works that have been
held during each refurbishment, a list of “common
duties” was drafted. This list shows the size of the
works that have been completed. The list is as fol-
lows:
1.- Demolition of the internal partition and disman-
tling of all Mechanical, Electrical and Plumbing
(MEP) services.
2.- Repairation of timber joist, wherever it was
needed.
3.- Placement of a properly levelled floor, meaning
that it will correct the common differential settlement
of the structure.
4.- Installation of new MEP and erection of new dis-
btribution, according to the inhabitant’s needs and
respecting local laws.
5.- An improvement of insulation of the entire perime-
ter closings that is floors, external walls and ceilings.
6.- Finishing.

DATA INTERPRETATION
Which are the reasons that have pushed to think that
a refurbishment based on BIM and CNC technology
is needed? The main reason is an overall inefficient
performing of the whole refurbishment work. In the
monitored cases in Bilbao, there facts can be joined
up in two main groups:

On the one hand, there is a general lack of skills to
achieve a task properly. This lack has been detected
among all the partakers of the refurbishment, which
includes the contractor and all workers.
On the other hand, the architect loses the control over the work being developed, unless he or she is in the building site for the whole day. The architect can't guarantee with 100% certainty that the projected building requirements have been properly delivered.

All this derives in many problems. Some of the works had to be repeated. The planned timing suffered several delays. In the analyzed samples, just two processes were considered to finish in the scheduled period. A 70 sq m apartment should be properly finished in 3 months. But some of them were finished after 12 months since the first demolition started.

A lack of skill of the contractor (frequently with a tricky way to think) can be a problem in the accuracy of the project. They tend to drop prices easily. But they normally ask for more money in order to finish despite a contract is signed between all the parts involved in the work.

All ten apartments had an increase in the budget. Just two of them had increased less than ten percent. In two of the cases, the budget has increased in between 10 and 15 percent. In the rest of the cases, the budget has increased somewhere around 20 percent.

The budget of these refurbishment cases, varied from 450 Euros per sq m to 650. The variation depends on the type of installation and the quality of the finishing.

It is quite difficult or it could take a big amount of time to make an accurate comparison between the refurbishing costs in Basque Country and in the UK. The published research by BCIS¹⁰, show that refurbishing costs are quite similar. Although there are some disparities in some of the budget units, the overall cost of refurbishing can differ around 5-10%.

**Structural damage**

A reinforcement of the structure was needed in all the cases. Most of the times, joist were reinforced with steel beams. The area affected with rotten joist never reached the 20 percent of the total area of the apartment.

Probably, a bigger problem is that the structure is not rigid enough, which means that it has differential settlements. In the worst of the cases, there were 30 cm of level difference between one point of the floor and the other.

This differential settlement will be increased unless there is a stiffening of the whole apartment floor. It has to be said that this kind of buildings have an irregular geometry and it is quite difficult to introduce prefab elements into them. Unless the measurement is really accurate, materials are manipulated in the building site.

![Fig.1. Typical steel reinforcement of the timber floor joists. Image by Kepa Iturralde.](image)

**Accessibility**

Every living unit should be accessible by anyone without any help. But sometimes it is quite difficult to reach that objective. In three of the analyzed cases, there was a lift installed in the apartment block. In another four cases, it could be quite simple to install a lift, because there was enough space around the staircase. In the rest of the three cases, installing a lift would mean losing inner space in the apartments.

There is quite a different situation in the Terraced Houses. The home unit here starts in the front door. The owner of the Terraced House has the opportunity to install by himself a lift. But, probably it’s an element too expensive to install and maintain for just one home unit.

**Collateral effects of the refurbishment**

Refurbishing processes create a building situation that is mostly anything but optimal. The demolition process itself shows the partial poor condition of the building. The building moves sufficiently enough to create disturbance. In all of the monitored cases, there have been justified complaints from the neighbours. The reasons of these complaints have been:

1.-Due to the movements caused by the demolition of the inner partitions, some cracks appear in the upper floor apartment’s walls. None of the cases have been dramatic or important, but the owner of the upper flat asked for a reparation in seven cases out of ten. These cracks appear even if some provisional reinforcement of the structure is placed. In one case, the movement was so strong, that a mirror in the upper floor fell from the wall. All this is quite normal considering that the structure elements are not rigid enough. The reinforcement should be placed before the main distribution is demolished. This way, the structure gets more rigid and the movements due to demolition could be minimized.
2.-The ceiling of the downstairs apartment collapsed partially in five cases. This occurred where the joists were in a bad condition and removing them was necessary. The plaster ceilings are usually attached to the timber joists. So whenever is necessary to remove the joist, part of the ceiling falls down.
3.- Neighbours complained about the generated noise in all cases. During refurbishment periods, every kind of finishing is removed which works as an insulator. This temporary lack of insulation is really noticeable whenever a worker has to manipulate an element in the site.
4.- The staircase of the apartment block suffers an unpleasant treatment during the refurbishment works. Scratches, stains, and overall dirtiness were produced. In four cases out of ten, there were several repairs to be made in the staircase to return it to its previous situation.
5.- In all ten cases, new MEP services or equipment was installed. Some of the cases, the neighbours presented their complaints because somehow they feel affected. Particularly, the new ventilation outlet and tubes were a cause of a discussion.

If we compare this situation with the Terraced houses, the collateral effects can be minimized. There are less shared elements with neighbours. The properties are divided with the vertical “party walls” and there is no horizontal property border. So, it is quite clear that the less the apartments share, the less annoyance are felt.

**REFURBISHING WITH BIM AND CNC**

Using this refurbishing process should change with the use of the new technology. Probably, nowadays schemes could be changed into a more automated process. It may be quite common thinking that the automation in the building site should increase costs and budget. This might not be totally true. First approaches show that, increase will be around 10-20%. This overrun of the budget could be reduced or limited if the link between the BIM software and the CNC fabricating process was somehow systematized.

**Defining an ideal situation for the elderly people**

When dealing with the refurbishment focused in aged people, some special goals have to be accomplished. It means that besides the general goals for refurbishment, which are: improvement of the insulation, reparation of the structural damages or energy saving measures. It has to be said that all the new equipment and distribution has to be installed in a rapid way and this process has to create minimum disturbance. The specific needs for the aged people in a refurbishment can be these:

1.- Everyone should reach every stage or floor with mechanical help. This means that a lift should operate in every apartment block.
2.- The new distribution of the apartment should be designed properly for the people who may have some difficulty. For instance, it’s recommended that doors, bathrooms, bedrooms and kitchen should be designed for disabled people. The design of the apartment should facilitate a self-management.
3.- If some extra equipment is installed, this should be integrated in the overall design concept and it should be friendly.
4.- The apartment should be easily restored into a new situation. All the distribution and the equipment should easily be moved or removed. People’s life situation change and the apartment distribution should not be an impediment to adequate to that change.

Taking into account all the mentioned points, a research has been developed to find a more systematized refurbishment process. BIM and CNC technology can be a useful tool to improve every task during the process. Some very first design steps have been made.

**Measurement and tolerances**

A proper refurbishment process grounded on BIM and CNC technology needs to be based in a detailed and exact measurement. Even more, it should be advisable to make more than one data collection during the refurbishment process because the timber-framed building could move some millimeters. To avoid related problems, the CNC fabricated pieces should offer measurement tolerances in order to facilitate the assembly and staging process.

The CNC fabricates the pieces with extreme accuracy. The measurement in the building site has to be really accurate in order avoid having problems when assembling the elements. Therefore, the measurement process is as important as working with BIM or fabricating the pieces with the CNC.

Measuring a hundred year old building formed by load-bearing walls and inner wooden joists can be a tough task if there a proper tool is lacking. Once the data are collected, the designer or architect should have interpreted them properly, identifying and giving a property to each element.

It is not the purpose of this article, neither to the background research, to define new measurement processes. Instead, the last approaches 4-8,10 in this field will be taken into account. A test in real situation should be proved if those devices are profitable for the implementation of BIM and CNC technology. It has to be said that measuring and testing the movements that the different elements have suffered are really important to the whole process. All walls, beams and joists may be twisted due to tension and torsion forces, and they shouldn’t be considered as simple linear elements. A no-destructive timber structure monitoring system could be ideal.
The previous research in this field has been focused mostly on masonry walls. In order to make a bigger step in the development of the “Refurbishment System”, the structure’s differential settlements should be collected.

But besides measuring the geometrical characteristics of the structural elements, the 3D data collecting should consider achieving the material’s resistance property. In the old buildings, material has suffered much pathology that can cause structural deficiencies. All these pathologies should be repaired and a level of the damage has to be measured in order to proceed properly.

In order to keep control over the works, several measurements should be done during the refurbishment process. The measurement could be classified in three groups:

1.-Measurement made before the demolition that should be used to draft the preliminary project. This measurement should be used to design, produce and assembly the structural reinforcement.

2.-Once the structure is reinforced, the distribution could be dismantled. A new measurement could provide a certainty to produce the enclosure elements.

3.-In the end and after the enclosure elements are assembled, a final measurement should be needed in order to fix the final finishing.

In order to achieve a rigid structure, tolerances between the junctions have to be minimized.

**Drafting the project**

In these first steps of the definition of a refurbishment system, making the project takes long time, since all the joints must be designed in 3D. This delay in the design process will be reduced when the BIM library of details is set-up.

In a common refurbishment process, projects are usually really simple. It means that the budget, the local planning standards and the client’s requirements force an austere use of resources. One architect by him/herself can draft this kind of project in five working days.

Instead, drafting the project using BIM and designing all the building elements would take us around three weeks of work. The main reason behind this delay is that each element has to be placed and tailored for the specific geometry of the building. In order to avoid designing each of the elements every time, some patterns are needed. The ongoing research should resolve and facilitate the adjustment of the elements to the required geometry. Probably a new software solution will be needed.

Besides that, using BIM software can be a proper tool to prevent quarrelling or even claims with neighbours, once some ventilation pipes are installed. Using BIM facilitates the understanding of the project. If any neighbour considers that some change will affect his apartment, it can be discussed clearly before.

In a way to avoid damages in the staircase, the building elements can be designed in accordance to the staircase size. If there is any doubt if the stair is big enough, a demo can be made using BIM software.

**Element production in CNC**

Once the project is drafted and the elements are defined, a CNC machine needs a model to mechanize. In other words, the CNC mechanizes an element out of a model that has been previously generated.

It has been estimated that near 1,400 different elements have had to be mechanized for the refurbishment of an apartment of 70 sq m. To generate a model for those 1,400 elements can be a tedious work. Each mechanization model should be automatically generated from the BIM model. Some of the software programs enable the link between the BIM model and the CNC machine, but as a rule, a specific CAM or plug-in will be necessary in order to link both the BIM model and the CNC machines. The work load will decrease considerably with the automation.

Besides, there are some facts that should be taken into account when designing a mechanized element. One fact is that the mechanizing or milling time should be as short as possible. Nowadays, some CNC machines operate with time and form simulator so we can predict how many time will be necessary to fabricate all the pieces used in the refurbishment process.

How to make a standardized junction among pieces is going to be another fact of discussion. One choice is to mechanize the elements for the use of traditional bolts. But nowadays there could be another...
choice to that solution. Some CNC welding techniques have brought new expectance to the area. CNC machinery characteristics and the output mechanized element are totally linked. Before a design of a mechanized element is drafted, it should be necessary to know what kind of CNC machinery we are going to work with. The available CNC machinery should be defined, before any design has been made.

**Assembly**
The main task when assembling is to fix every part to its correct and proper place. How can all these pieces be levelled in place following a systematized way? Somehow we need a “sneaking” or a checking device that can tell us if the element is correctly placed. This “sneak” could be based on the last technology using global positioning systems or another Metrologic device.

**Quantity of material used**
A comparison has been made between traditional refurbishment process and the one which is proposed. It is difficult to quantify the material in a virtual case. The very first design approaches made by BIM show that the quantity of material used in the traditional way or by the new system can be similar. If the aim is to design a more sustainable building refurbishment process, it is quite important to economize the use of material. This concept is quite important if we want to achieve an environmentally friendly refurbishment process.

**Maintenance**
BIM can be an efficient tool for the future maintenance of the apartment. A “BIM as built” concept should be defined. This BIM as built could serve for the future retrofitting of the apartment. This new retrofitting could be designed and drafted with the BIM software and the CNC could produce all the required elements as well. In the very first designs, it has been important that most of the installation pipes should run between the joists and the new reinforcement guides. This way, the new retrofitting process could be more flexible.

**Looking forward an efficient design**
As it has been said before, the definition of the “Refurbishment System” is in the very first process. Many tests have to be made, particularly in real situation. There is still a long way to go. In a way, the recent approaches define somehow an appropriate direction that should be followed.

It seems that the key factors to achieve an efficient refurbishment of this kind of buildings are as follows:

1. Formal and functional convergence: the structural reinforcement and the guides of the ceilings and floors.
2. These guides should probably be made in steel L and U profiles with light sections that could work better than others. There must be a trial to work with some other materials, such as laminated wood and aluminium.
3. In the analyzed samples, the refurbishment was limited to the apartment. The property system in Spain is oriented to an inhabitant owned apartment. This fact hinders the refurbishment of the whole building. This means that this kind of refurbishment is limited to the physical constrain of the upper stage’s floor and the lower stages ceiling. Everything has to be made within that limit.
4. The refurbishment work has to be independent to any other work that some other neighbour would do, meaning that the system used in the apartment shouldn’t involve or implicate any other member of the apartment block.

**CONCLUSION**
A common refurbishment process is based on low efficient systems. Time and money are often wasted. Therefore, new approaches are needed in order to improve the situation. Implementing BIM software and CNC technology in this kind of work can be a choice. It seems quite clear that before introducing or implementing in a systematized way the BIM and CNC technology, some other steps have to be achieved. Instead, the whole process will still have a crafting character to it. Briefly, it can be said that in the measurement field, 3D data collection should be made in a simpler or more systematized way, and
this should be proved useful to the assembly process as well. In the software field, the different programs should be more interconnected or linked, both between them and with the rest of the process.

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References
The adoption of Industrialised Building System (IBS) 
construction in Malaysia: The history, policies, 
experiences and lesson learned

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Purpose Industry and government in Malaysia coined the term industrialised building system (IBS) to describe the adoption of construction industrialisation, mechanisation, and the use of prefabrication of components in building construction. IBS consists of precast component systems, fabricated steel structures, innovative mould systems, modular block systems, and prefabricated timber structures as construction components. Parts of the building that are repetitive but difficult – and too time consuming and labour intensive to be casted onsite – are designed and detailed as standardised components at the factory and are then brought to the site to be assembled. The construction industry in Malaysia has started to embrace IBS as a method of attaining better construction quality and productivity, reducing risks related to occupational safety and health, alleviating issues for skilled workers and dependency on manual foreign labour, and achieving the ultimate goal of reducing the overall cost of construction. The chronology of IBS-adoption in Malaysia goes back a long way, reaching back to the 1960s, when precast elements were adopted in the building industry to address the problem of an acute housing shortage. However, the introduction of IBS was never sustained beyond this period. As a result of the failure of early closed-fabricated systems, the industry is now avoiding changing its construction method to IBS. Some of the foreign systems that were introduced during the late 1960s and 1970s were also found to be unsuitable in Malaysia’s climate and not very compatible with social practices. IBS has regained its popularity presently due to problems with construction workforces where the industry has been relying for a long time on unskilled workers from neighbouring countries.

Method In 1999, the IBS Strategic Plan was launched to promote the system’s usage in the industry. This was followed by the IBS Roadmap 2003-2010 and IBS Roadmap 2011-2015; these are blueprints for industrialised construction by 2015. The roadmaps have been developed by the government to chart progress and guide the awareness programmes, incentives, vendor scheme development, training, quality control and research and development programmes. The government also took the lead in 2008, by mandating that all public-sector projects must attain no less than 70% IBS-content under the Treasury Circular SPP 07/2008. This policy aims to build up momentum and to establish demand for IBScomponents, thus bringing the cost down.

Results & Discussion At present, IBS-construction is widely used as a mainstream method and the implementation has moved from prefabrication towards mechanisation, automation, and robotics applications. This paper highlights some of the history, policies, experiences, and lesson learned in adopting IBS in Malaysia. The outlook for IBS-implementation in Malaysia is bright, but much work is still needed from the government to convince the contractors, manufacturers, and suppliers to adopt IBS-construction.

Keywords: construction, industrialized building systems, Malaysia

INTRODUCTION

Industrialised Building System (IBS) is the term coined by the industry and government in Malaysia to represent the adoption of construction industrialisation and the use of prefabrication of components in building construction. IBS is defined as a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site work (Hamid et al., 2008; CIDB, 2007; CIDB, 2005 and CIDB, 2003). It consists of precast component systems, fabricated steel structures, innovative mould systems, modular block systems and prefabricated timber structures as construction components (CIDB, 2003). Parts of the building that are repetitive but difficult – and too time consuming and labour intensive to be casted onsite – are designed and detailed as standardised components at the factory and are then brought to the site to be assembled (CIDB, 2003). The onsite casting activities in IBS utilise innovative and clean mould technologies (CIDB, 2007; CIDB, 2005 and CIDB, 2003). In the Malaysian context, the classification by the CIDB is widely used and well understood by scholars and practitioners. CIDB has classified the IBS systems into five categories as depicted in Table 1 (CIDB, 2003).
Table 1: IBS classification (CIDB, 2003)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Descriptions</th>
</tr>
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<tbody>
<tr>
<td>Precast concrete framed buildings</td>
<td>The most common group of IBS products is the precast concrete elements; precast concrete columns, beams, slabs, walls, 3-D components (e.g. balconies, staircases, toilets, lift chambers, refuse chambers), lightweight precast concrete, as well as permanent concrete formworks.</td>
</tr>
<tr>
<td>Formwork System</td>
<td>Considered as one of the low-level or the least prefabricated IBS, as the system generally involves site casting and is therefore subject to structural quality control, the products offer high-quality finishes, and fast construction with less site labour and material requirement.</td>
</tr>
<tr>
<td>Steel Framing System</td>
<td>Commonly used with precast concrete slabs, steel columns and beams, steel framing systems have always been the popular choice and used extensively in the fast-track construction of skyscrapers. Recent developments in this type of IBS include the increased usage of light steel trusses consisting of cost-effective profiled cold-formed channels and steel portal frame systems as alternatives to the heavier traditional hot-rolled sections.</td>
</tr>
<tr>
<td>Prefabricated Timber Framing System</td>
<td>The system consists of timber building frames and timber roof trusses. While the latter are more popular, timber building frame systems also have their own niche market, offering interesting designs from simple dwelling units to buildings requiring high aesthetical values such as chalets for resorts.</td>
</tr>
<tr>
<td>Blockwork System</td>
<td>The construction method of using conventional bricks has been revolutionised by the development and usage of interlocking concrete masonry units (CMU) and lightweight concrete blocks. The tedious and time-consuming traditional brick-laying tasks are greatly simplified by the usage of these effective alternative solutions.</td>
</tr>
</tbody>
</table>

The construction industry has started to embrace IBS as a method of attaining better construction quality and productivity, reducing risks related to occupational safety and health, alleviating issues for skilled workers and dependency on manual foreign labour, and achieving the ultimate goal of reducing the overall cost of construction. Apart from this, it offers minimal wastage, fewer site materials, a cleaner and neater environment, controlled quality, and lower total construction costs (Pan et al. 2008, Hamid et al. 2008 and Pan et al. 2007). Already utilized in Malaysia since 1960s, IBS is the way forward for the industry stakeholders to make leaps and bounds progress in the Malaysian construction industry. Sufficient exposure and incentives are pouring in to encourage industry players to make a paradigm move – from conventional to IBS construction.

**THE CHRONOLOGY OF IBS ADOPTION IN MALAYSIA**

1. Development of IBS in post-independent Malaysia:
   IBS has been introduced in Malaysia since early 1960s when Public Work Department (PWD) and Ministry of Housing and Local Government (MHLG) of Malaysia visited several European countries and evaluate their housing development program (Thanoon et al. 2003). In 1963, the government sent a group of architect from PWD to learn industrialised building in some of European countries. The following year, another group of architect from the Federal Capital Commission was sent to France for about 6 month for exposure in industrialised buildings (Sumadi et al. 2001). In the same year, Ministry of Housing and Local Government (MHLG) was being set up by the government to concentrate to development of housing. The ministry officers and representatives visited West Germany, Denmark and France to gather more information on industrialised building later that year (Sumadi et al. 2001).

2. Development in 1964 to 1970s:
   After their successful visit in 1964, the government had started its first IBS project aims to speed up the delivery time and built affordable and quality houses as stipulated under the 2nd Malayan Plan 1960-1965 and the 1st Malaysian Plan 1966 – 1970. About 22.7 acres of land along Jalan Pekeliling, Kuala Lumpur was dedicated to the project comprising 7 blocks of 17 stories flat consists of 3000 units of low-cost flat and 40 shops lot. This project was awarded to JV Gammon and Larsen and Nielsen using Danish System of large panel pre-cast concrete wall and plank slabs. The project was completed within 27 months from 1966 to 1968 including the time taken in the construction of the RM 2.5 million casting yard at Jalan Damansara. In 1965, the second housing project initiated by the government comprising 6 blocks of 17 stories flats and 3 block of 18 stories flats at Jalan Rifle Range, Penang. The project was awarded to Hochtief and Chee Seng using French
4. Development in 1980s to 1990s:

The 1980s period (Trikha and Ali, 2004) saw several pilot projects in Malaysia through the 1970s to develop precast concrete sandwich wall panels (CIDB, 2005). At the same time, recent innovations in construction methods led to the industrialisation of building systems, which were introduced during the late 60s and early 70s. Many of these systems were not suitable for Malaysia's tropical climate and social practices. Newer and better technologies were constantly being introduced than the building design was very basic and not considering the aspect of serviceability such as the local needs to have wet toilet and bathroom (Rahman and Omar, 2006).

3. Development in 1970s to early 1980s:

In 1978, the Penang State Government launched another 1200 units of housing using prefabrication technology. Two years later, the Ministry of Defense (MOD) adopted large prefabricated panel construction systems to build 2800 unit of living quarters at Lumut Naval Base. As one can observe, IBS was engage at first place in the construction of low-cost high-rise residential building to overcome the increasing demand for housing needs. Many construction in at this time utilised precast wall panel system. Nonetheless, the industrialisation of construction was never sustained in this period. Failure of early closed fabricated systems had resultant the industry to avoid of changing their construction method to IBS. Some of the foreign systems that were introduced during the late 60s and 70s were also found not to be suitable with Malaysia climate and social practices. Newer and better technologies were constantly being introduced than in the market since wet joint systems were identified to be more suitable to be used in our tropical climate and it was also better to utilise the bathroom types which were relatively wetter than those in the Europe (CIDB, 2005). At the same time recent innovation the form of precast concrete sandwich wall panels developed in Europe, has received wide acceptability in countries having hot temperature climates due to better insulating properties resulting in a cooler in door environment and has been send in several pilot projects in Malaysia through 1970s to 1980s period (Trikha and Ali, 2004).

4. Development in 1980s to 1990s:

During the period of early 80s up to 90s the use of structural steel components took place particularly in high rise buildings in Kuala Lumpur. The usage of steel structure gained much attention with the construction of 36-storey Dayabumi complex that was completed in 1984 by Takenaka Corporation of Japan (CIDB, 2003 and CIDB, 2006). In the 90s, demand for the new township has seen the increase in the use of precast concrete system in residential buildings. Between 1981 and 1993, Perbadanan Kemajuan Negeri Selangor (PKNS) a state government development agency acquired pre-cast concrete technology from Praton Haus International based on Germany to build low cost houses and high cost bungalows for the new townships in Selangor (CIDB, 2003 and Hassim et al. 2009). It was recorded then, around 52,000 housing units was constructed using Praton Haus system (Trikha and Ali, 2004) and the state of art pre-cast factory was set up in Shah Alam (Sarja, 1998). Other than the use of Praton House technology from Germany, PKNS was also embarked in other IBS systems at the same period; Taisei Marubumi - large panel are cast in factory using tilt-up system where one panel forms the base for next panel cast (1,237 housing units and 11 shop lots at PJS), Hazama system (3,222 flat units and 1,112 housing units at Bandar Baru Bangi), Ingeback system which is Swedish system using large panels in vertical battery mould and tilt-up table mould (3,694 flat units) All the project were constructed by local contractor with international technical support from established international firms in joint venture partnership (Hashim et al. 2009 and Sarja, 1998).In that period IBS used in Malaysia are large panel system (housing project in Shah Alam and Taman Brown), metal form system in Wangsa Maju, Pandan Jaya and Taman Maluri and modular systems which are heavily promoted by CIDB in government project. Although the system originated overseas, local contractors has made modification to suit local requirement. Instead of steel, high quality film coated plywood shuttering is used in an innovative mould system. The form can be easily dismantled and handled by small crane and can be adjusted to suit architectural requirement (Sarja, 1998). Other systems are framing system, modular system and partially pre-cast system (the Cemlock Built System which is originate in Australia and used by the National Housing Department in Pekan Selama housing project) (Sarja, 1998).

5. Development in 1990s to 1998s

In this booming period of Malaysian construction 1994 -1997, hybrid IBS application used in many national iconic landmarks such as Kuala Lumpur Convention Centre (steel beam and roof trusses and precast concrete slab: Victor Buyck Steel Construction), Lightweight Railway Train (LRT), KL Sentral Station (steel roof structure and precast hollow core: RSPA – Bovis), KL Tower (steel beams
and columns for tower head: Wayss and Freytag), Kuala Lumpur International Airport (steel roof structure; KLIAB – Eversendai) and Petronas Twin Towers (steel beams and steel decking for the floor system – Mayjus JV and SKJ JV). The booming period of construction during that time includes the development and construction of new administration capital of Malaysia; Putrajaya and Cyberjaya. Both cities are the massive development areas consist of new government buildings, business boulevard and residential area, and most of them were built in IBS or a hybrid IBS, combination between IBS and conventional construction.

At this state, the use of IBS as a method of construction in Malaysia is evolving. Many private companies in Malaysia have teamed up with foreign expert to offer solutions to their IBS projects (Eastern Pretech, BPB Malaysian Gypsum, Lafarge and Duralite). Many had acquired enough knowledge through technology transfer to build up own capacity in IBS technologies (PKNS Engineering, Setia Precast and Global Globe). Setia Precast and Global Globe using technologies first adopted by Taisei Corporation of Japan. In fact, Malaysian was also developed their own IBS technologies (Zenbes, CSR, IJM Formwork, Pryda, Baktian and HC Precast). The local IBS manufacturers are mushrooming, although the facilities yet to operate in full capacity. The IBS system is largely used for private residential projects in Shah Alam, Wangsa Maju and Pandan, Dua Residence, Taman Mount Austin and Tongkang Pecah, Johor. It used in public residential projects in Putrajaya Prescient 17 and Prescient 9, PPR Sungai Besi, Sungai Bedaun, and Telipok, Sabah. The new generation of building that utilised IBS is better in term of quality, and architectural appearance compared to the earlier generation. IBS is also widely used to construct government’s schools and teachers housing complexes (Kuala Kangsar, Yan and Sungai Petani), hospitals (Serdang Hospital and UKM Hospital), collages and universities (Penang Matriculation Collage, UiTM, Kuching and University PETRONAS and University of Malaysia Sabah), custom and immigration complexes (Kelana Jaya and Johor Bahru), private buildings (Weld Tower, Maju Perdana, Traders Hotel, City Square and Olympia Tower, Jaya Jusco, IKEA) and police quarters (Senawang). The IBS agenda was further boosted with the 2004, 2005 and 2006 Malaysia Budget announcements. In 2004, new government building projects had been strongly encouraged to have at least 50% of IBS content in their construction elements which had been calculated using IBS Score Manual developed by CIDB. Furthermore, in 2005, the government had pledged to construct 100,000 units of affordable houses using IBS (Hamid et al. 2008). Finally, in 2006, a tax incentive was offered through Acceleration Capital Allowance (ACA). IBS manufacturers would be given ACA for expenses incurred in the purchase of steel moulds used for production of precast concrete components to be claimed within three years (CIDB, 2005 and Shaari, 2006).

7. 2008 - Present
One of the most important milestones of IBS policy is regulation on the use of IBS in the construction of public buildings. In November 2008, the Treasury Malaysia issued a Treasury Circular Letter, now referred to as SPP 7/2008, to all Malaysian government agencies directing them to increase the IBS contents of their building development projects to a level not less than 70 points of the IBS score and in that sense IBS must be incorporated as part of the contract document for tender (Hamid et al. 2008). The circular letter took effect immediately and the Implementation and Coordination Unit (ICU) of the Prime Minister’s Department has been given the task of monitoring the level of compliance to this directive by the respective agencies. The decision was to create sufficient momentum for the demand for IBS components and to create a spillover effect throughout the nation. To monitor the implementation, the government established the National IBS Secretariat. It involves coordination between inter-ministry levels to make sure the policy is successfully implemented. During a period from October 2008 and May 2010, about 331 projects under 17 ministries were awarded and constructed using IBS (CIDB, 2010). The majority of the projects were construction of public schools, hospitals, higher learning institutions and government offices throughout Malaysia. The total cost of the projects was about RM 9.6 billion (CIDB, 2010).

EXPERIENCES AND LESSONS LEARNED ON IBS CONSTRUCTION IN MALAYSIA
1. There is a change in paradigm regarding IBS in Malaysia in the past few years. In the past, the majority of contractors and industry stakeholders still divided either to use IBS or conventional method although the benefits of IBS are clear and eminent. But this is not the case now, the industry, nowadays has to think of a system to be implemented in their project (weather it conventional or IBS) due to the increase need of quality end-product and speed of construction, and coping with the issue of foreign workers. In the case of public building projects, the industry is instructed to use IBS system. So, the industry both in the private and public construction projects has no other choice but to be involved in IBS and adopt industrialisation in construction. (In November 2008, the Treasury Malaysia issued a
Treasury Circular Letter, now referred to as SPP 7/2008, to all Malaysian government agencies directing them to increase the IBS contents of their building development projects to a level not less than 70 points of the IBS score and IBS must be incorporated as part of the contract document for tender. The decision was to create sufficient momentum for the demand for IBS components and to create a spill-out effect throughout the nation. Due to this policy, the cost of constructing in IBS has reduced significantly. The adoption in the past was normally based on wanting rather than by viability. IBS system in Malaysia is now, mostly competitive if not cheaper if one compare it to the conventional practices depending on type of projects, type of systems and volume.

2. The IBS in Malaysia promotes open system or hybrid system and encourages full industry participation compared to the prefab closed system where only limited industry companies can participate. IBS supply chain should comprise of modular component-based products that can be produce and interchangeable between any project thus promote mass customisation at the customers end. Therefore, a company that can utilize the IBS supply chain will enable it to sell systems rather than selling single products. Standardising the construction industry is a critical factor in establishing an Open System in Malaysia. The concept of the OBS is similar to what has happened in the ICT industry whereby through standardization of jointing parts such as USB ports, consumers can buy computer equipment such as mouse or scanner anywhere in the world. The equipment can then be easily installed by the users as the connection from the equipment to the computer has been internationally standardised.

3. One of the important milestones in IBS Roadmap 2003-2010 was the introduction of Modular Coordination (MC). MC is a concept of coordination of dimensions and space where buildings and components are dimensioned and positioned in a basic unit or module known as 1M which is equivalent to 100 mm, as stipulated in MS 1064, and developed in 2000. The concept allows standardisation in design and building components. It encourages participation from manufactures and assemblers to enter the market, thus reducing the price of IBS components. Modular need to be adopted to cut down the waste in IBS. However the implementation of modular coordination requires better design planning.

4. Malaysian construction industry is very good in modifying and adopting IBS technologies captured from oversea practices. Many private companies in Malaysia in present day have teamed up with foreign expert to offer solutions to their IBS projects. Many had acquired enough knowledge through technology transfer to build up own capacity in IBS technologies. Many world-class Malaysian developers have chosen IBS over the conventional methods for important projects such as the Petronas Twin Towers, Putrajaya, KL Sentral and KLIA. There is ample evidence that the failures of past construction systems are due to blind acceptance of foreign products that were not open (flexible) and were unsuitable to our climate and culture.

5. Successful IBS contractors as observed are not a user of technology or limit its role as project manager and assembler. Most successful IBS contractors have an in-house manufacturing and design capacity. They also invest in and sometimes invent systems, and so do not just depend on existing manufacturers. The also partner with oversea partners to acquire the technologies.

6. One of the major issues of IBS is on changing users’ perception. Users tend to think that IBS buildings is easy to leak and can not be renovated. However, through the advancement of technologies and better planning and design, IBS buildings/housings in the present days have improved in term of performance and can be renovated by users.

7. Some of the foreign systems that were introduced during the late 60s and 70s were also found not to be suitable with Malaysia climate and social practices. Newer and better technologies were constantly being introduced than in the market since wet joint systems were identified to be more suitable to be used in our tropical climate and it was also better to utilised the bathroom types which were relatively wetter than those in the Europe.

8. IBS in Malaysia is seen as a threat to traditional methods but in reality many IBS technologies like block works is exist together with conventional practices. The failure of IBS to penetrate the market is due to a misconception that it will eventually replace the traditional sector, while it actually should work closely in tandem to promote best practice in construction. The sharing of best practice between the two approaches is essential for the continued successful development of both construction sectors. IBS should be looked by the industry as easy, simple and cost effective solutions to the players.

9. Each IBS system has its own advantages and limitations. The selection and implementation of correct technology in IBS projects is perhaps the key to IBS success. There is a need to realise that precast concrete IBS is not suitable for every project. If more people were aware of its capabilities and available technology, they could identify particular system that suited the project. The advantages of IBS systems in Malaysia are as follows:

**Barriers to IBS Adoption in Malaysia**
1. Currently, the incentives for IBS are not sufficient. IBS adoption requires more pull and push factors from the government. Due to the small profit margin, the change from conventional to IBS was not feasible, unless, more attractive incentive systems and benefits which can lure the conventionalist to IBS are in place.

2. The availability of cheap foreign labour which offsets the cost benefit of using IBS is a root cause of the slow adoption in the past. As long as it is easy for the industry to find foreign workers, labour rates will remain low and builders will find it unattractive to change into simplified solutions such as IBS.

3. The limited take up also relates to sheer cost of investment and the inadequacy of market size. Since the Asian financial crisis in 1997 and global recession in 2008, it becomes apparent that large investments in central production plants are uneconomical.

4. To use a higher level of IBS, the adopters require a huge volume of works to break even on the investment. Although it creates more value to construction, it is literally a more expensive option due to the paid up capitals and maintenance of machineries. Inconsistency of volume over time and lack of business continuity resulted in the investment in latest innovation not being commercially sustainable.

5. Low standardisation of components also hinders successful use of IBS. The tailor-made components which do not fit into another project will increase initial costs due to the cost of the mould and design. Lack of standardisation was due to a lack of a certification and accreditation scheme on IBS and the lukewarm response to Modular Coordination (MC) promotion under MS 1064.

6. There is a general consensus among practitioners that IBS needs mass production to achieve economic viability, but currently, in Malaysia, there is no assurance of continuity of production, thus limiting interest in IBS.

7. Supply Chain Management (SCM) and partnering concept has not been fully understood by the industry. Currently, the cooperation between contractors, manufacturers and suppliers is weak in many cases. Improving the procurement system and supply chain is the key to achieving IBS success for contracting companies.

**The Way Forward**

The lesson learnt on IBS construction in Malaysia has led to the following recommendations towards the future improvement of IBS adoption in Malaysia:

1. The rising sustainability awareness around the globe has put the construction industry under immense pressure to improve project efficiency and deliverables. Industrialised Building System (IBS) has the potential to promote sustainability development and green construction. This may be achieved from a controlled production environment, minimization of construction waste, extensive usage of energy efficient building material, a safer and more stable work environment, and possibly better investment for long term project economy. The industry need to seize this opportunity and use IBS as their competitive advantages in promoting sustainable construction.

2. The mass construction workforce, especially the locals, needs to upgrade their skills to be involved in IBS. The policy on labour focuses on encouraging personnel to acquire skills in more than single trade. This would add more value by providing a more skilled workforce which would ultimately enhance the competitive advantage of the industry in facing the issue of adoption from conventional to the IBS. They must be equipped in design, installation and project management skills which are critical to IBS. A comprehensive preliminary study should be conducted by the government to identify the skill gaps in the IBS sector in order to create a comprehensive and systematic training programme.

   The preliminary study will ensure that the training fits the needs of IBS organisations and accommodates current skill shortages in the market, particularly specialist skills such as design and installation, based on information from real practice.

3. A vendor development programme modeled along the lines of the development of the national car industry should be established to target delivery of building components for the construction. The vendor program is to be accredited by existing government agencies which can provide a vetting process not only to guarantee consistent quality but also the achievement of structural capacity, fire rating and other requirements. The selected vendor are to be provided training, seed capital, components design, and selected private sector consultant to start up production factories. The location of this vendor’s manufacturing plant has to be located in the areas with available labour. Based on educated assumption, the expected investment requirement of RM 1.25 million is considered within the reach of SMEs and small contractors displaced by the new technology. A system is to be developed such that building component accredited will be given green lane approval such that technical and non-technical legislation that hinders implementation of the new technology will be removed. The government can help by conducting market research to ascertain market opportunities to the vendors. The vendors also need inventory management consultancy and advice and development of better tools and infrastructures required for location of manufacturing plant.

4. Manufacturers and all players of IBS sectors need to create highest value for IBS to serve the
clients best interest, as we know clients in a private sector are more demanding in term of design esthetic value. With this regards, we need to move from mass production of components to mass customisation of buildings where the building design can be tailor-made to specific customer needs. The industry shall need to encourage automation and robotic to be really reduce the use of workers in construction and prefabrication. The government also perhaps needs to encourage manufacturers to produce ‘modular housing’ which move all the work trade at site to the manufacturing floor. We need to move up the level of industrialisation and encourage innovation, whilst low innovative systems which do contained enough value like mould systems will be discouraged. Proper incentive and tax holiday need to introduce to cater the production of innovative IBS.

5. Malaysian IBS contractors need to benchmark IBS technologies, lesson learnt and best practices from other countries. Construction industrialisation is a worldwide agenda. IBS is already successful adopted in Finland, Sweden, Japan, Germany and Singapore where offsite technologies had eventually modernised and improved the industry. This research recommended the industry players to find ways to capture and disseminate technologies, lesson learned, and best practices from successful countries and companies to expedite our learning curve on IBS and to guide the way forward. The government should launch a forum on a regular basis of academics and associated practitioners active in IBS for exchange of information and experience, development of new techniques and advice on promotion and implementation of IBS. An online portal was also suggested to disseminate international trends, products and processes associated with the IBS.

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MDA-based facility management applications under BIM

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Purpose: The recent research trend of building information modelling (BIM) involves interoperability and issues pertaining to the design, construction, operations, and maintenance phases of a building. However, few researchers are concerned with problems encountered in the last two phases of the building life cycle. Since BIM has been widely used in the design and construction phases, further expanding the BIM data stream to the post-construction phase can not only establish a consistent, shared database for information exchange between the phases but also assist in current facility management applications. This research reconceptualises BIM with object-oriented thoughts to a space-based representation, and tries to construct an interface between BIM and existing facility management software.

Method: Model-driven architecture (MDA) is one of the modern software design approaches. With its foundation – meta-object facility (MOF) – and model transformation, MDA provides an ideal solution for easily maintaining the interoperability. In this research, a MOF of a building is constructed by imitating the MDA approach, encapsulating BIM data and providing an interface for external facility management software. This MOF of a building is designed with spatial interference due to the maintenance and repair work usually based on the space.

Results & Discussion: A conceptual demonstration of disaster mitigation is conducted to test the feasibility of using MDA to encapsulate BIM data for extended applications. Furthermore, the expected results are reconstructing maintenance records to a space-based database for a better software design and a solution for interoperability.

Keywords: information technology; BIM; model-driven architecture; facility management

INTRODUCTION

Building Information Model (BIM) technologies promise to provide a consistent communication and information exchange platform for all stakeholders involved in a building life cycle, as well as to create a 3D display environment to clarify a building’s virtual representations. Many researchers study BIM-related issues, such as design and engineering, linking to analysis tools, energy innovations, facility management, and so on. However, most studies concerned with the design and construction (D&C) phases of a building, few studies deal with issues pertaining to the operation and maintenance (O&M) phases.

In O&M phases, many applications, such as disaster mitigation (which can be regarded as the most important field in the building industry), security, community care, require building information in a different way within the AEC industry, but these extended usages are seldom considered in BIM. Also, in these fields there is mature software for their applications, and BIM cannot cover all the fields which need building information as a possible input. As a result, the proposed approach suggests to follow the open/closed principle (OCP) – “open for extension, but closed for modification”. For example, structural elements in a building will not be changed during their entire life cycle; and thus, it may be a good way to operate such information just at the class level, not at the metaclass level to avoid future modification. For example, a house has four rooms. These four rooms should be represented as four classes, and their objects should represent the conditions at specific time instances. The traditional IFC-based approach treats these four rooms as four instances; and thus, applications in the O&M phases cannot operate at the correct level to seamlessly retrieve information from the D&C phases.

Government agencies usually retain a copy of building blueprints and related documents of D&C phases. However, they are seldom updated unless special reasons. In O&M phases, disasters are hard to be predicted and may occur in different forms, and fires may be the most common form in a building environment. Investigation of fires may be conducted after a fire occurs, and fire scene reconstruction is one of important parts. Currently the Fire Dynamic Simulator (FDS) performs well and is widely used for it, but a good database may be needed to store correlated data. The proposed approach may provide a new model for properly retrieving information from BIM and for being able to store fire investigation data in the BIM-derived model, so a preliminary research result presented here can show how to deal with the interoperability issues of the information flow between the design/construction phases and the operations/maintenance phases.
RELATED WORKS

Nowadays, the software development process is facing the situation that requirements become more complicated and different platforms can be chosen as the working environment. To solve these problems, MDA was proposed by Object Management Group (OMG), mainly for the purpose of integration and interoperability. This approach basically implements software development by using formal models.

In MDA, models occupy a significant position. Generally, model is used to describe and simplify the real world. Furthermore, metamodel is needed to define the description of a model. Take paintings for example, as shown in figure 1, a painting can be viewed as a model of a real world thing; actually, it is composed of lines and shapes, therefore, these shapes are the model description which is necessary to form a painting. In the higher layer there may also exists other abstraction to describe M2 layer.

![Common models](image)

To take an overview of MDA, at first the separation of concerns should be introduced. Three MDA viewpoints of a system are described as follows: (1) Computation Independent Viewpoint (CIV), (2) Platform Independent Viewpoint (PIV), and (3) Platform Specific Viewpoint (PSV). CIV contains none of the computer-related processing details and only focuses on the business requirements; PIV is about the operations of a system but does not contain the details for a specific platform; PSV integrates PIV with the details of using a particular platform as the development environment.

As shown in Figure 2, four layers and their transformation mechanisms are identified based on these views. A computation independent model (CIM) is constructed from CIV. Based on the CIM the platform independent model (PIM) is created. With a sufficiently complete and precise PIM, platform specific model (PSM) can be generated by model-to-model transformation mechanisms, and the specific code model – which can be viewed as implementation – can be automatically transformed from PSM. OMG defines a standard – Meta Object Facility – to provide metadata management and modelling language definitions. MOF is used with a metamodel hierarchy shown in Figure 3. A run-time system can be interpreted by a UML model, since the UML model is design by people, there can be many UML models from different perspectives. To describe a UML model, we need to define UML descriptions and notations as a communicating method. The UML definitions are also based on the definitions of MOF. With the descriptions of higher layers, the lower layer can be clearly explained.

![MDA Process](image)

![Metamodel hierarchy](image)

RESEARCH APPROACH

Because of the wide use of BIM, building information is available for stakeholders in the O&M phases. However, the data structure is not easy to be used
for users, and needs extra efforts to write programs for further use of this information. In order to offer a better way for the extended use, this research defines a metamodel hierarchy of building to interpret elements of a building. Figure 4 shows the sample definitions of the metamodel hierarchy of a residential building. This hierarchy is designed as the basis of the proposed approach.

M3 layer
For different perspectives, the contents in M3 layer should be viewed as different roles. Inside this hierarchy, the M3 layer describes basic components of a building, such as doors, walls, windows, and so on. These components exist in any type of building, in other words, they are essential for a building; as a result they are designed to be in the M3 layer. Outside this hierarchy – which means extended applications without sufficient understanding of the building internal structure and BIM programming – for them, the layers below and those basic components are encapsulated due to OCP. Building information is available for them through the “BuildingSuperObject” but its data structure cannot be changed from the outside, that is, “BuildingSuperObject” is an interface as a communicating bridge.

M2 layer
This layer inherits basic components from the M3 layer, as well as different types of buildings and their basic units are described here. Different types of buildings may have rooms/zones/spaces for different purposes, and rooms are classified by purposes as a basic unit. For example, an apartment is classified as one type of residential buildings. Bedrooms and living rooms may only exist in a residential building, not in a factory.

M1 layer
In the M1 layer, a “model” means a specific building and is constructed here. Most of the static components are inherited from higher layers. Also, the constant spatial components of a building are described here, since most of the time the floor plan of a building will not be changed after the D&C phases.

M0 layer
Finally, the instances of M1’s building are stretched by time as a timeline and record the whole life cycle, which means the building information covering the D&C phases to O&M phases exists in this layer.

Suppose BIM data of a specific building is available. First its spatial relationship and the usage of spaces are re-drawn as the model shown in the M1 layer of Figure 4. The class library of this building can then be automatically generated by the model. Since attributes are also predesigned to be contained in the model, extended applications can use data they need through the model.

As shown in Figure 5, the metamodel hierarchy of building is simplified as the bold rectangle, and an interface is connected with the top layer – BuildingSuperObject. Those applications need not
to know the operation of the hierarchy; also, the applied domain is changeable. This design provides flexibility of the proposed model. It can be used not only for one specific application, but for providing better flexibility and reusability.

**EXAMPLE**

![Diagram of hierarchy]

![Diagram of apartment building 'B']

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Since the more floors and rooms a building contains, the more complicated the problem is. A three-floor apartment is presented in this section as a simple example to show the contents in metamodel hierarchy of an apartment building 'B'. Some details are also omitted for clearly interpreting the proposed approach. The relationship between contents and the expected application of the metamodel hierarchy are also interpreted in this section.

Figure 6 presents a sample model constructed following the metamodel hierarchy in previous section. In apartment building 'B', there are three floors and an elevator. There are two households in each floor, and the rule of the address assignment is the floor number, plus the serial number. Each household is assumed to have three rooms, i.e., living room, bedroom and toilet. In Figure 6, rooms in address '02' are omitted. These rooms inherit attributes from their designed usage respectively. In addition, from the spatial perspective, 'B' can be viewed in two dimensions: horizontal and vertical. The horizontal dimension is equivalent to the floor concept; the vertical dimension, named "slot" here, is composed of rooms located on the same vertical line. Usually the floor plan of a household is the same as its neighbour upstairs or downstairs in an apartment; therefore, rooms of the same purpose belong to the same slot. However, the elevator is independent of a floor or a slot since it is movable.

The model described above becomes a basis for automatic code generation; a class library of 'B' is constructed for extension. The extended applications can use BIM data through this model – more specifically, users of these applications access BIM data through this model instead of directly operating with BIM. Since it is not easy to cross the threshold of the programming issues for BIM applications, it is believed that using this model will assist the development of extended allocation for BIM.

As suggested before, now building information is reconstructed to a spatial-based form. The fire investigation result can be store in BIM room by room and with the spatial relationship, such as slot and floor, it
can also perform several simple spatial inference function, for example, the charred facility may indicate how the fire go through.

CONCLUSIONS
This research has proposed a software architecture to integrate the static (BIM) information with the dynamic, O&M-related data. The MDA technique was utilized to store and synthesize the data. The BIM information is used to show the geometry aspect of the building. MDA has been also applied to other industries' applications, including the AEC industry. Further enhancement of the system is needed in order to integrate more dynamic information from different domains correlated with O&M phases and/or other BIM programs.

References
Applying building information modelling in environmental impact assessment for urban deep excavation projects

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Purpose  Due to the rapid development of cities, underground structures, such as deep excavations and tunnels have been widely used to increase underground space. Since these underground structures are often adopted in old and crowded town area, accidents may easily make serious damage to adjacent structure and even some casualties. Professional engineering knowledge and experience can reduce or avoid this chain of events. But it is undeniably the case that in more complex urban engineering environments, risks are higher. Construction project teams must therefore consider a wide variety of information when managing risks and making project decisions. Urban deep excavation construction might cause unfavourable effects on the ground and to nearby structures. Environmental impacts need to be evaluated and monitored during the deep excavation construction. Generally, construction project teams will set up monitoring instruments to control and monitor overall environmental status, especially when retaining wall construction, retaining wall excavation, and during groundwater pumping. Voluminous monitoring data and project information are usually created along the delivery processes of construction. It is difficult to view and manage them comprehensively.

Method  Our research employs the concept of building information modelling (BIM) in environmental impact assessment for urban deep excavation projects. BIM is a relatively new technology that facilitates better information integration and management. Many engineering companies employ BIM for information integration, visualization, and parametric design, to reduce both the duplication of work and the complexity of interface integration. In this research, a 3D-building model, an excavation model, environmental conditions, the results of ground surface settlement analysis, and measurement and monitoring data, were integrated into our system to assist construction project teams to execute environmental impact assessment accurately. The risks and issues affecting safety of excavation and nearby structures might be recognized earlier through conveying information visually in this system. Construction project teams can then handle them immediately. The implementation of the system was carried out in the MicroStation Visual Basic for Applications (MVBA) environment. The Bentley MicroStation supports visualization of the 3D-model and provides some capabilities for 3D-object manipulation and information query.

Results & Discussion  This system can provide construction project teams a full view of the ongoing project, along with functions to integrate and display information multidimensionally. We will demonstrate the functionalities we developed and verify its feasibility in the O6-underground station of the Kaohsiung metro system.

Keywords: BIM, environmental impact assessment, deep excavation, monitoring

INTRODUCTION  Due to fast development of the city, underground structures, such as deep excavation and tunnel have been widely used for increasing of underground space. Since these underground structures are often adopted in old and crowded town area, accidents caused by them may easily make serious damage to adjacent structure and even some causality. Especially, ground settlement is thought to be the greatest impact for nearby environment. At present, the empirical methods and finite element method are two commonly used tools to predict the ground settlement induced by excavation. Through collection and evaluation of data of surface settlement from underground construction in various places, Peck 1 first defined the possible influence zone next to the excavation. Bowles 2 recommended a procedure to estimate excavation-induced ground surface but lateral wall deflection has to be first calculated. Clough and O’Rourke 3 proposed various types of envelopes of excavation-induced ground surface settlement and they are mainly classified by ground conditions. Ou et al. 4 developed a method to predict the ground surface settlement on the basis of studies and type of ground surface settlement and it was concluded that in principle there are two types of settlement curves, the spandrel and the concave and it appears the magnitude of wall deflection in cantilever model would define the type of settlement curve. Similarly, various studies have been conducted so far for application of numerical analyses in deep excavations but they are not addressed here due to the limit of paper length. Professional engineering knowledge and experience can interpret the above mentioned
results to avoid and reduce the accidents occurring. But, it is not to be denied that design and construction of deep excavation becomes more difficult as excavation depth is deeper and surrounding environment becomes more complicated. Therefore, the construction project team must consider a wide variety of information to assess environment impact when managing risks and making project decisions. Treicher\(^5\), an experimental psychologist, has proved that of the information human beings received, 83% is by sight sense, this shows the information visualization is essential for communication and information distribution. With the growth of using visualization techniques in construction, Building Information Modeling and Geographic Information System have recently attained a widespread contribution in visualization of construction progress\(^6\). Especially, BIM is a relatively new technology that facilitates better information integration and management. Many engineering companies employ BIM for information integration, visualization and parametric design, to reduce both the duplication of work and the complexity of interface integration. For these reasons, this research applies BIM in integrating the relevant data (ex. 3D building model, excavation model, stratum data, monitoring data, the results of ground settlement analysis and so on) in urban deep excavation projects for environmental impact assessment. Moreover, BIM system can convey the different kinds of information for assisting construction project team to manage risk and make project decisions.

**METHODOLOGY**

The number of deep excavation pits in city centers is increasing every year. Buildings, streets, surrounding excavation locations and design of very deep base-ments make excavations formidable projects. Deep excavation projects are widely understood as high-risk events, and so much attention to safety and stability is required. This research took advantage of BIM functionalities in environmental impact assessment for urban deep excavation projects. The concept is to integrate the required data and then to visualize them appropriately and effectively to assist construction project teams to effectively assess environment impacts as shown in Figure 1. Further discussion of the information requirements for each aspect will be presented in the following section.

**Building Information Modeling**

BIM becomes a shared knowledge resource to support environmental impact assessment. The sources of integration in BIM in this research are as follows:

- **Project Data**
  
  Project data is required for project participants to understand the background information of the project, such as the project name, address, owner and the construction company.

- **3D Model**
  
  BIM technology currently focuses on the visualization of the changing status of the 3D shapes during the construction process. Therefore, this research integrates the different types of 3D models into the BIM system which includes the building model, excavation model, retaining wall model and supporting elements for visualization.

- **Stratum Data**
  
  The excavation performance differs according to different ground conditions. This system integrates soil properties and groundwater statuses for environmental impact assessment.

- **Analysis Data**
  
  Generally, construction project teams will analyze and predict ground settlement using the empirical methods and finite element method before deep excavation. In this research, these results were integrated and visualized in the BIM system to help construction project teams assess environmental impact in a synthesized manner.

- **Monitoring Data**
  
  Construction project teams normally set up various types of monitoring instruments to collect the necessary data to monitor the status of different environmental variables. The related data integrated into the BIM system includes type, standard value and units recorded by the field monitoring instruments.

In this research, three easy-to-use modules are developed to provide the core services of environmental impact assessment.

**Safety / Risk Management**

Adequate risk management during construction is dependent on accurate and on-time reporting of the key measures from the intensive monitoring system. The system can evaluate the probable environmental impacts from the critical monitoring data and BIM, and enable construction project teams to identify and manage risk. Furthermore, the 3D objects (building, excavation and monitoring instruments) are highlighted in different colors according to their risk statuses.

**Information Distribution**

Effective visualization assists people in obtaining the required information effectively and efficiently. This system was designed to not only provide sufficient information to facilitate project management, but also provide the various visualization tools to assist with impact assessment and communication.
Monitoring Data Management
The goal of monitoring is to provide useful scientific information about the status and trends of various factors affecting the project’s environmental impact. Comprehensive data management functionality is thus essential for achieving this goal, particularly for urban deep excavation.

Environmental Impact Assessment
Ground surface settlement can occur during three construction stages: (1) retaining wall construction; (2) groundwater pumping and (3) main excavation. Therefore, project teams need to detect or predict the environmental impacts of these stages to prevent accidents from occurring. This section discusses the environmental impacts and zones of influence associated with the three stages mentioned above, as shown in Table 1. Subsequently, it is shown that how this research integrated these empirical formulas into our BIM system to assist construction project teams in evaluating construction statuses through various visualization tools.

Retaining Wall Construction
According to the monitoring results of the rapid transit system in Hong Kong, after the completion of the diaphragm walls and before the main excavation, the accumulated deformation was found to be 40–50% of the total deformation after the completion of the main excavation. Clough and O’Rourke found that the ratio of the maximum settlement induced by the construction of diaphragm walls to the depth of the trench was 0.15%, according to in-situ monitoring results.

Groundwater Pumping
According to investigations, most problems encountered in deep excavation have direct or indirect relations with groundwater. Groundwater-induced problems in an excavation may arise from insufficient investigation of groundwater or geological conditions. Thus, it is necessary to perform detailed investigations of groundwater and its influences on soils or structures during excavation.

Excavation
Observing the shapes or types of ground surface settlement, we can see that soil at the back of the retaining wall moves forward and down with the retaining wall deforming under normal conditions. Ground settlement will thus be produced. Peck proposed that the influence zone of settlement should be two or three times that of the excavation depth. Clough and O’Rourke proposed that excavation in sandy soils may induce a zone of influence of settlement about twice that of the excavation depth.

System Design and Implementation
The system is implemented based on commercial hardware and software comprising the Bentley MicroStation and InRoads, which supports visualization of the 3D model with some capabilities for 3D object manipulation and information query, with Application Programming Interfaces (APIs) for functionality extensions.

Data Integration and Processing
As shown in Figure 2, this research designed and developed an integrated BIM model to describe and store information for the entire project, including 3D models, stratum data, analysis data, project data and monitoring data. All of them can be divided into two types, non-graphic data which is stored into a database and 3D geometry which is stored in the MicroStation object model (.dgn file). Each object (graphic element) that is linked to a database has a database linkage attached to the element. Sometimes, this is called the MSLINK in Bentley System. Therefore, users can double-click the 3D object in MicroStation and summon detailed information on the database that was extracted from the database and vice versa. Besides, monitoring instruments update frequently, so the system needs to provide a batch input function to effectively deal with a large number of monitoring data at any one time.

Visualization
This system provides three styles of visualization for communication among the project participants as follows: (a) 1D Visualization: attributes of objects and
general project information; (b) 2D Visualization: graphs and charts of different variables and objects; (c) 3D Visualization: 3D models of building. The visualization examples are shown in Figure 3. We also defined three colours to visualize the different risk statuses in the 3D environment. The different kinds of monitoring instruments are represented by the different 3D primitive solids shown in Table 2. Table 3 shows the color scheme implemented for displaying risk status.

Table 1. Construction Stages v.s. Environmental impacts

<table>
<thead>
<tr>
<th>Construction Stage</th>
<th>Diagram</th>
<th>Environmental Impacts</th>
<th>Monitoring Data</th>
<th>Influence Zone</th>
</tr>
</thead>
</table>
| Retaining Wall Construction | ![Diagram](image) | Pile-driving induced ground shock leads to cracking in adjacent structures and settlement. | 1. Building Settlement Point (SB)  
2. Settlement Point (SM)  
3. Tiltmeter Point (TI) | \( d = 0.5H_t \)  
Where \( H_t \) is the depth of a trench \(^{10}\) |
| Groundwater Pumping | ![Diagram](image) | Pumping causes lowering of ground water table which increases the effective stress on soft clay and results in consolidation settlement. | 1. Settlement Point (SM)  
2. Standpipe Piezometer (PS) | \( Q = \frac{2\pi r_k (s_1 - s_2)}{\ln(r_2/r_1)} \)  
\( Q \)=Discharge Quantity  
by Theis(1935) \(^{11}\) |
| Excavation | ![Diagram](image) | Excavation causes excessive wall deflections which may then induce adverse movements to adjacent foundations, leading to large surface settlement, and cracking of pavements. | 1. Building Settlement Point (SB)  
2. Settlement Point (SM)  
3. Tiltmeter Point (TI) | \( PIZ_1 = \min(2H_e, H_g) \)  
\( H_e \) =The excavation depth and  
\( H_g \)=The depth of the hard soil.  
\( PIZ_2 = \min(2H_f, B) \)  
\( H_f \) = the depth of the soft clay bottom and  
\( B \) = The excavation width.  
\( PIZ = \max(PIZ_1, PIZ_2) \) \(^{12}\) |

Table 3. Color schema for risk management

<table>
<thead>
<tr>
<th>Color</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Safe.</td>
</tr>
<tr>
<td>Yellow</td>
<td>Warning. Please adopt mitigation measures to reduce the risk level.</td>
</tr>
<tr>
<td>Red</td>
<td>Dangerous. Please take adopt mitigation measures urgently to reduce the risk level.</td>
</tr>
</tbody>
</table>

Table 2. The 3D representation of monitoring instruments

<table>
<thead>
<tr>
<th>3D Solid</th>
<th>Description</th>
<th>3D Solid</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td>Building Settlement Point (SB)</td>
<td><img src="image" alt="Diagram" /></td>
<td>Standpipe Piezometer (PS)</td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td>Settlement Point (SM)</td>
<td><img src="image" alt="Diagram" /></td>
<td>Tiltmeter Point (TI)</td>
</tr>
</tbody>
</table>
DEMONSTRATION

Engineering Example

Excavation of O6 station in Kaohsiung metro system was selected as the project background. Kaohsiung is the economic and political centre of southern Taiwan, its metro project of the city was commenced since 2001. The O6 Station is located in the junction of Chung-Cheng Road and Ming-Chu Road and the surrounding of O6 Station is populous as shown in Figure 4. It was constructed by cut-&-cover method and the maximum excavation depth is 19.6 m. The pit was retained by a 1m thick, 36 m deep reinforcement concrete diaphragm wall. The major structure of O6 Station is a 2-level basement. The main soil strata of the site consist of the groundwater level was observed at 3.5 m below surface level. Details of the project are stated by Hsiung. In such a complex environment, construction project team must pay more attention on environmental impacts during deep excavation. Instruments installed on site include inclinometers in soils and diaphragm walls, settlement points, tiltmeters, piezometers etc.

Safety / Risk Management

Stratum data is integrated and visualized in the BIM system, as shown in Figure 5(a). These ground conditions are important references for selecting the appropriate excavation method. Adopting suitable excavation methods can reduce risks. Moreover, the BIM system can visualize the zone of influence of deep excavation (developed by the previous researcher), as shown in Figure 5(b). It can provide essential information for assisting planners in assessing environmental impacts comprehensively for safety and risk management.

Monitoring Data Management

The construction project team can input monitoring data from the graphical user interface or database, as shown in Figure 6(a). The system will subsequently update the status representation of environmental impacts by comparing field values and standard values, as shown in Figure 6(b). The construction project team can also view the overall status of the excavation project, as shown in Figure 6(c).

Conclusions

Risk assessment is an important task for urban deep excavation projects. This research took advantage of information integration and visualization capabilities of BIM to assist planners with assessing possible environmental impacts. This study demonstrated the use of the BIM model of a deep excavation project to integrate the 3D model and the relevant information about retaining walls, excavation and adjacent buildings, and then visualized all of the results of analysis and assessment to show the likely locations and degrees of risk and safety, under different situations, so that users can quickly obtain the necessary information to make the necessary decisions and evaluations to solve problems and plan appropriate emergency measures.
Fig. 5. Safety / Risk Management

(a) Stratum data for environmental impact assessment
(b) Zone of influence of ground surface settlement

Fig. 6. Monitoring data management

(a) Monitoring data management
(b) Visualization of monitoring statuses
(c) The monitoring overview

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Automation of modular design and construction through an integrated BIM/lean model

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Purpose This research proposes an automated model for the design and manufacture of modular construction that applies both Building Information Modeling (BIM) and lean concepts on a modular construction manufacturing (MCM) process and gaining the benefit of both concepts. Method This integration involves transferring generated data from a BIM model to the manufacturing phase where ‘Lean’ is applied to the factory production line. Although translating and synchronizing data are essential to applying these concepts successfully, automation of the construction process has yet to be fully realized in the construction industry. Interoperability of the heterogeneous applications used in the domain of modular construction manufacturing can best be achieved by using generalized and standardized representations of the needed product and process data, thereby enabling faster and better management and decision-making. However, even though various solution approaches have been proposed in the last decades to integrate building information and lean principals, a general approach based on a standard BIM is still missing. In this research, the project components’ schedule and quantity take-off list, which are required for applying ‘Lean’ to the production line, are categorized and extracted from the BIM model using IFC (Industry Foundation Classes) customized programming, and stored in a database placed in a data server. Then the Value Stream Map (VSM) is generated based on both existing database and defined lean criteria. Results & Discussion A simulation model is developed to evaluate the generated VSM. The proposed methodology is validated by a case study in Edmonton, Canada, called The Compassion House. The existing Compassion House is a 2-storey building with a basement and the new project is an extension for the existing building. The architectural design for the building included a modular construction capability, so the entire building was divided into modules. The application of an automated model on the design and manufacturing process of the case study illustrates the effectiveness of the proposed methodology in reducing waste, time, and, resource usage.

Keywords: automation, modular construction manufacturing, BIM, lean, simulation

INTRODUCTION The increased interest in industrialization of the building construction process demands special methods of design and manufacturing process to support automated production operations. Factory production provides opportunities to apply Lean thinking strategies for production efficiency in the plant including eliminating waste and supporting the delivery of wider variety of products, which are more responsive to customers’ preferences in a shorter time and at a lower cost. To support the manufacturer’s needs for design and drafting considering Lean thinking in construction, an integration method of Building Information Model (BIM) with Lean construction principals is required. Although the concept of incorporating Lean and BIM is not new, automating the process of data transfer from design to production stage in the modular construction manufacturing (MCM) is still missing. The real benefits of BIM can be obtained when building information is used through all phases of the project. Since no single tool or application domains can fulfill all the project phases’ requirement, the integration of different application domains is required through the project life. However, in the past decades, data exchange was possible only through customized translators for specific applications or manual translation from one application to another, where often the information is restructured by the receiving application. According to a research conducted in the United States by McGraw Hill, 8 in 10 users of BIM tools state that lack of interoperability between applications is considered as a limitation to obtain the real benefits of BIM 1. Interoperability is defined as the ability of various applications and organizations to exchange and share information together 2. The interoperability of various changes in the components of models that are created by different software or applications is required by creating a common link in BIM. Compat-ible models created by different software or applications require translation into a single file format in order to transfer object’s information correctly 3. A format that can be applied in the construction industry as a resource for interoperability is the Industry Foundation Classes (IFC) schema which is recognized as the common data exchange format for interoperability, developed and maintained by buildingSMART International. IFC is in the process of
becoming an official International Standard ISO/IS 16739.  

IFC creates a set of specification of the model’s information to provide a neutral environment for interoperability throughout the project lifecycle, between different disciplines, and various applications. IFC represents project properties including geometry, relations, processes and material, performance, fabrication, and other specifications which are essential for design and construction. IFC implementations provide access for the software developers to the highly structured object model used in BIM tools through the application programming. This research proposes an integrated model that applies both BIM and Lean on the modular construction manufacturing process based on the Industry Foundation Classes (IFC) schema. The project components’ schedule, and quantity take-off, which are required for applying Lean on the production line is categorized and extracted from the BIM model in a CAD (Computer-Aided Design) tool using the IFC customized coding. Sequentially Value Stream Map (VSM) was generated in order to depict the production line layout and schedule, base on the information from the 3D model (BIM) and defined Lean criteria. A simulation model is generated to validate the proposed VSM for a building which is constructed by Landmark Group, a residential construction company in Edmonton, AB, Canada. The results of the generated simulation model was compared with the real case and proved the effectiveness of the proposed methodology. In this research, advanced methods and techniques in productivity efficiency are integrated where a new methodology is created for manufacturing construction.

BACKGROUND ON BIM, LEAN, AND IFC

BIM and Lean are two distinct concepts in the construction industry and each impacts the construction process differently. Although the two areas are independent and are separately applicable to the construction process, benefits can be maximized by integrating both BIM and Lean concepts. In the following section, each concept is briefly introduced with emphasis on characteristics which highlight the interaction between Lean and BIM. The phrase “lean” is used in Lean production because everything is used less compared to mass production. Lean Production was developed by Toyota led by Engineer Ohno to demonstrate waste reduction in Toyota production system (TPS). Waste in Lean production is also related to performance from the customer point of view. According to Womack and Jones, Lean principals are defined in five steps: (1) Specify value as perceived by the customer for each specific product; (2) Identify the value stream; (3) Make the value flow without interruption through the value stream; (4) Let the customer pull the value from the value stream; (5) Strive and pursue perfection. The Lean production concept was adopted in the construction industry in 1992 through Koskela’s seminal report. The focus for Lean construction, same as that for TPS, is on reducing waste, increasing the value for the customer, and continuous improvement. Lean based production methods focus on the value stream in which value, as defined by the customer, is continually added to a product. BIM provides the basic data which can be used as input to Lean based production. Additionally and based on the definition in the BIM Handbook, BIM provides requirements for new capabilities in construction and supports the creation of an integrated design and construction process that increases quality, and reduces the cost and duration of a project. BIM is applicable to all of the project stages and helps reduce waste from the design conceptual stage to the construction and further to the operations. There are additional benefits of using BIM particularly in applying Lean to the construction process. The procedure of generating shop drawings is simpler for any building type once the model is generated completely. First a model is created in BIM, and then the schedule for building components, material ordering, fabrication, and the delivery process are developed. The idea of integrating Lean and BIM is not new; Rischmoller et al. used Computer Advanced Visualization Tools (CAVT) to improve the value generation in design and construction processes. They used Lean principles as the theoretical framework to evaluate the impact of CAVT in waste reduction, better customer value, and improving construction flow. Khanzode et al. introduced and applied the concepts of Virtual Design and Construction (VDC) to represent aspects of BIM in Lean Project Delivery Process (LPDS). They explained which specific VDC tools and methods can be applied to each phases in LPDS to achieve the objectives of a Lean production system. Sackes et al. compiled a set of requirements based on the Last Planner System, called KanBIM to implement a BIM-based Lean production management system. The KanBIM concept provides visualization of the construction product as well as the production process which enables construction managers to focus on establishing production systems and continuous improvement. Moreover several IT systems integrating various application domains have been developed to obtain networked-based environments for effective inter-organizational project collaboration addressing different project phases, the developed solutions largely lack generality in terms of data interoperability. Integration of project information is based on the specific internal data models of the used component systems, and not on generally applicable and hence standardized data models. All this significantly de-
creases flexibility, multi-stakeholder collaboration, and inter-enterprise cooperation 19. In this research, the existing gap between the data captured in the BIM model contained in an IFC project model on the one side and their association to the Lean on the other side via applying automation principles, is considered. Despite the ability of BIM in developing an integrated model by creating object-oriented tools, there are still limitations on the widespread use of building information models such as involving all the project team and integrating the generated information. Accurate communication between different specialists across disciplines, and over the project lifetime requires standard approaches 20. The main data exchange format in construction industry for BIM files is Industry Foundation Classes. A web-base remote data server provides a mechanism to openly exchange data 21.

The IFC is considered as a framework model that provides a publicly available data schema consist of project information from feasibility and design, through construction and operation and supports exchanges of this range of information 22 as illustrated in Figure 1. IFC depicts all information associated with a building by providing a broad range of generic building object types (beam, column, wall, and slab) with associated attributes and properties, also several shape definition methods and means to describe relations between objects 23.

![Fig.1. IFC schema](image)

Although the IFC data model has been available over a decade, and the intentions of using IFC is laudable for many software developers, the significant impact on the broad problems of IFC in AEC has yet to be addressed. Proposed solutions to overcome these problems can be seen via: (1) defining workflows used in practice, (2) defining specific information exchanges within different application domains, (3) defining appropriate model views for the exchanges. This is the focus of the national BIM standard (NBIMS), administered by BuildingSMART within the National Institute of Building Sciences (NIBS) 24. In the NBIMS approach, group of experts in AEC specifies “use cases” called information delivery manuals (IDMs) associated with their domains 25. On that basis the implementation-oriented model view definitions (MVDs) can be defined, in order to provide the information specifications needed to enable software developers to write appropriate export and import translators 24.

**PROPOSED METHODOLOGY**

The common data sharing process between applications in a BIM framework involves exporting a file from application A and then importing the file into application B as shown in Figure 2. The challenge with this method is it causes multiple copies of the same data 3.

![Fig.2. Current practice](image)

The identified solution is based on Service-Oriented Architecture (SOA) where data can remain on application A and be used or modified by application B. For this purpose, a server is developed in a Web-based environment as a core system where the generated data is stored and provides a communication platform for various IT domains through this data server as shown in Figure 3. The model’s components are defined as IFC functional type, geometry, attribute, and relation in the data server. Any further changes to the components’ specification in the data server affect the applications and changes are applied automatically. Therefore there is no need to change each model created in different software tools separately, instead changes are applied through the database placed in the data server to all the linked applications.

![Fig.3. Proposed schema](image)

The suggested method would be through dedicated model views. In this approach only subsets of the
The main focus is on the partial specific exchange occasions. As expressed by Eastman et al., the main focus is on the partial information exchange instead of transferring a complete model, in order to provide flawless interoperability.

To accommodate the proposed Integration methodology requirements in this research, the add-in of Autodesk Revit® Structure, which is a computer tool for the design of wood framing structure, is used to generate the BIM model and building components’ schedule. The BIM model is uploaded to the developed data server where generated data are categorized in order to specify particular data that are required to be exchanged between other applications such as IFC Takeoff™ for Microsoft Excel® and BiMserver™. After generating the output of BIM Model, the Value Stream Map (VSM) of the factory is developed based on the components’ schedule through a proposed method called Integrated Process Improvement (IPI) using Lean principles to reduce waste over the factory activities.

The proposed methodology and associated components is presented in Figure 4. The BIM model inputs are including wall, floor, ceiling, door, window, and MEP (mechanical, electrical, and piping drawings) information along with modular concept and selected framing method. The BIM model is generated considering (1) criteria including modules’ dimension, available equipments, sustainability, and constructability and (2) standards including ISO standards, material specifications, city bylaw, and national building codes. Architectural components are represented through the 2D layout of the project. Based on the production resources specified in the building Codes (Cf. National Building Codes of Canada (NBC) issued by the Institute for Research in Construction). Structural requirements are specified with building codes and are used to define the components for each wall, floor, ceiling, door, and window. Modular concept defines a set of rules for modules’ dimensions and the layout division into units based on road regulations, acceptable dividing elements, and cranes’ capacity.

In the main process, the Revit structure wood framing extension, frames out walls to generate takeoffs, building components’ schedule, sections, elevations, and 3D view of the stud framing. After creating the BIM model, it is required to enable it to be a compatible model to be used by different applications. The Revit model is translated into the IFCXML-format and then uploaded to a developed database which is located in a data server, allowing for further processing and analysis. For this research, the BiMserver™ was chosen as the data server.

The data server is connected to IFC Takeoff™ for Microsoft Excel® and the information is transferred from the data server to an Excel spreadsheet. After developing a fully-detailed set of components’ schedule including type (wall, floor, etc.), dimensions, door and windows’ size and location, and other details, Lean production concept can be utilized to optimize the work flow in the production line based on the amount of work needed to be performed in each station. For this purpose, it’s required to prepare the Value Stream Map (VSM) of the production line through a proposed Integrated Process Improvement (IPI) method. The VSM is a core Lean tool; it is a technique that depicts the value adding flow of materials and information in the production process and helps to identify the non-value adding operations for making improvements. The IPI method addresses the following goals: (1) increase productivity, (2) reduce or eliminate waste, (3) standardize building processes, (4) reduce delays, (5) eliminate bottlenecks and unnecessary material handling, (6) raise skill levels, (7) reduce inventories, (8) address defects and problems, and (9) optimize space usage. A set of limitations need to be considered such as factory space limitation, available human resources, factory working hours, and customer demand scheduling.

In order to define the required work and measure the number of human-resources in each station, it is necessary to divide the work in sub packages and define the sequence of work. The building’s component quantity which is extracted from the spread
sheet along with the productivity and required man-hours which are accessible from historical data of the factory provide the required duration for the specific amount of work in each station. In this research, required duration for wall fabrication including nailing the stud, measuring the diagonal lengths, placing the sheathing, securing the drywall, cutting the openings for the doors and windows, and transporting to the next station was calculated automatically, and other required work in further stations are calculated based on the historical data of the duration in each station in the production line of the factory. Work duration in wall station was calculated based on the measuring method developed by Mulligen. According to his method, there is a significant variance in the duration of each activity. Therefore, data for each activity is collected from a time study and analyzed to determine the statistical representation of the total time of the activity represented by a probabilistic distribution. The probabilistic duration of an activity (PD) is calculated satisfying Equation 1, which is proportional to the total time of the activity as the number of workers remains constant.

Eq.1. Probabilistic Duration

$$PD = \frac{PTT}{W}$$

Where,

- PD = Probabilistic Duration (min)
- PTT = Probabilistic Total Time (min)
- W = number of Workers utilized

A probabilistic total time (PTT) for each activity is calculated satisfying Equation 2 based on the productivity per worker and the size of the wall.

Eq.2. Probabilistic Total Time

$$PTT = \frac{EL}{PP}$$

Where,

- EL = Effective Length (ft)
- PP = Probabilistic Productivity (ft/min)

Each wall is constructed uniquely with various components such as door, window, and stud. The effective length of wall (EL) is calculated satisfying Equation 3 which is the linear length of the wall plus the constant coefficients multiplied by each of the wall properties.

Eq.3. Effective Length

$$EL = LL + A \cdot d + B \cdot w + C \cdot s$$

Where,

- LL = Linear Length (ft)
- d = number of doors
- w = number of windows
- s = number of studs
- A, B, C = wall property coefficient

In the IPI process, the building components' schedule is analyzed and the VSM for the factory is created and shows the product family, information and material flow, work cell, inventory space, daily customer demand, supplier and shipping schedule, and production volume. At the end, a simulation model using Simphony.NET 3.5© runs the generated VSM to validate the produce results such as takt time, lead time, processing time, amount of work in process, buffer stuck, bottleneck, on time delivery percentage, and rework or defect rate. The simulation model is going through potential scenarios and finds a near optimum result.

IMPLEMENTATION

One type of building construction technology is modular building where the modules are manufactured in the factory under controlled conditions and transported to be erected on site. The use of manufacturing construction is directly influenced by the customer's requirements. Such construction technology can increase the effectiveness of advanced technologies such as BIM and Lean construction. The modular construction manufacturing (MCM) process consists of three main stages: panel prefabrication, production line in the factory, and on-site modules installation. The production line is divided into a number of stations, where all activities including framing, door and window, electrical, mechanical, and finishing can be done. Since the modules are fabricated in the factory, special method of design is required for this type of construction which can provide information that are required for setting the production line for the manufacturing.

For this research, Revit Structure was used since it includes an extension for wood stud framing that frame the walls, and generates take-off quantity without having the user to manually place every stud. Autodesk Revit also supports IFC files as an open source code enabling data exchange within a BIM workflow. Parameter sets or quantities to elements exported to IFCs can be modified and customized with user preferences. In this research, the proposed methodology was applied on a case study which is a wood frame modular building and was developed in Autodesk Revit structure wood framing extension. This case study was compared to a real case which is built by Landmark and developed in Sima®; the output of Sima is shown in Figure 5.
After developing the model in Revit, the information was transferred to the IFC format and was stored in a data server. According to this research purposes, it is not required to exchange the full set of information of the project at once, instead only a small subset of information is required, and updates can be transmitted frequently in a form of small packages of information as per the method developed by Boeykens. Through the translation process, the 3D object model is split to the components and creates the XML file. Figure 6 shows a panel in the Revit which provides information about the components such as panel size, location and size of openings, number of studs, and spacing.

These components are translated to IFC classes such as (1) spatial elements include IfcSite, IfcBuilding, IfcBuildingStorey, and IfcSpace, (2) physical elements include IfcWall, IfcBeam, IfcDoor, IfcWindow, and IfcStair, (3) structural analysis items, (4) materials include IfcMaterialLayerSet, and IfcMaterialProfileSet, (5) shape representations include IfcBody, IfcAxis, and IfcFootPrint, and (6) placement in space includes IfcLocalPlacement, and IfcGridPlacement. Building's components are covered under these classes and have unique properties that are stored in the data server and are transferable to other applications. In the BiMserver, required data to create the factory VSM are categorized and extracted as input of IPI process to optimize the work flow in the production line based on the amount of work needed to be performed in each station.

However, Landmark has incorporated interoperability by making the production line semi-automated where some of the stations are fully industrialized and the work is done by machines. Therefore, the created model in Sima is translated to software which is readable by machines called VupView as shown in Figure 7, and the machine go through the allocated job such as cutting, framing and nailing.

To create the VSM in the IPI process, work cells, work flow, and required man-hours for each cell were defined based on the Lean principals and project schedule as shown in Figure 8. All activities and their sequences in each cell were clarified and a mix of triangular and beta distributions for the process time of each activity were defined. In the next step, a simulation model using Simphony.Net3.5 was developed to simulate the production process based on that depicted in the future state value stream map. The model is capable of producing results for takt time, lead time, processing time, amount of work in process, buffer stuck, bottleneck, on time delivery percentage, and rework or defect rate. A satisfying simulation run demonstrates an attempt to eliminate muda (waste) from the system including delay, transportation, correction and rework, over-processing, inventory, over-production, and process flow disconnection.
The result for the processing time of one module to be fabricated in the factory is presented in Table 1. The result shows that one module can be fabricated between 2610 to 2752 working minutes (43.5 to 45.8 working hours) within 90% level of confidence. The probability density function (PDF) and cumulative density function (CDF) of the result is illustrated in Figure 9 and 10 respectively. With 95% level of confident, each module can be built in less than 45.8 working hours (5.7 days) that shows 11 days improvement compared to current process time in the factory which is 17 days before applying Lean on the manufacturing process.

<table>
<thead>
<tr>
<th>Name</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>5%</th>
<th>95%</th>
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<td>2682</td>
<td>2814</td>
<td>2610</td>
<td>2752</td>
</tr>
</tbody>
</table>

**CONCLUSION**

Uncontrolled conditions and work sites limitations have negative effects on the cost, schedule, and the project quality. Modular manufacturing is a solution for those challenges with new requirements in automating the design and manufacturing process for more effective results. BIM provides the opportunity for automating the design process. Factory production provides opportunities for applying Lean principals in the plant. To support the manufacturing needs with consideration of Lean thinking in construction, an integration of BIM with Lean is required. In this paper an integrated model that applies both BIM and Lean on the modular construction manufacturing process based on the Industry Foundation Classes (IFC) schema was proposed. The project components’ schedule, and quantity take-off, which are required for applying Lean on the production line was categorized and extracted from the BIM model in a CAD (Computer-Aided Design) tool using the IFC file format, and stored in a database which is connected to a data server. Sequentially Value Stream Map (VSM) was generated in order to depict the production line layout and schedule, base on the developed database and defined Lean criteria. A simulation model was generated to validate the proposed VSM. The results of the generated simulation model was compared with the real case and proved the effectiveness of the proposed methodology. In this research, advanced methods and techniques in productivity efficiency were integrated where a new methodology was created for manufacturing construction in reducing waste, time, and resource usage.

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Fuzzy Set-based Contingency Estimating and Management

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Purpose
Contingency estimating and management are critical management functions necessary for successful delivery of construction projects. Considering its importance, academics and industry professionals proposed a wide range of methods for risk quantification and accordingly for contingency estimating1. Considerably less work was directed to contingency management including risk mitigate during a project. Generally, there are two types of risks; (i) known risks which can be identified, evaluated, planned and budgeted for and (ii) unknown risks which may occur. These risks require a cost and time contingency, even if they were not planned for, in order to mitigate their impact in an orderly manner. In this respect, the importance of contingency management is critical in view of increasing project complexity and difficulty of estimating and/or allocating sufficient contingencies to mitigate risks encountered during project execution. This paper focuses on the contingency management from two perspectives; estimation and depletion of contingency over project durations. Method
A new method is developed using fuzzy sets theory2 along with a set of measures and indices to model the uncertainty inherent in this process. This method includes a possibility measure, an agreement index, a fussiness measure, an ambiguity measure and a quality fuzzy number index. These measures and indices provide not only the possibility of having adequate contingency but also address issues of precision and vagueness associated with the uncertainty involved. The paper also presents a comparison between the commonly used Monte Carlo Simulation method and the proposed direct fuzzy-sets-based method. As to depletion, the paper presents a management procedure focusing on depletion of the contingency in a generic computational platform. The developed procedure makes use of policies and procedures3 followed by leading construction organizations and owners of major constructed facilities. The developed method and its computational platform were coded using VB.NET-programming. Results & Discussion
A numerical example is analysed to demonstrate the use of the developed method and to illustrate its capabilities beyond those of the traditional Monte Carlo Simulation.

Keywords: Contingency, Management, Estimating, Depletion, Fuzzy set theory.

INTRODUCTION
Modeling uncertainties and quantification of risk are critical to successful management of engineering, procurement and construction projects. Generally, there are two types of risks; 1) known risks which can be identified, evaluated, planned and budgeted for and 2) unknown risks which may occurred. These risks required a cost and time contingencies, even if they weren’t planned for, in order to mitigate their impact in an orderly manner. Accordingly, it was recommended to divide project contingency fund into two components allocated and unallocated19. Contingency estimating and management become critical in view of increasing project complexity and difficulty of estimating and/or allocating sufficient contingencies to mitigate risks encountered during project execution. It should be noted that contingency estimating is commonly prepared prior to project execution; its management is an on-going process over project duration. There are several methods that deal with contingency estimation and allocation2,3,10,20. However, considerably fewer procedures and methods can be found in literature for contingency depletion and contingency management27,2,3. Comparing to estimating and scheduling it also noted, the models used to manage contingency are not formal, standardized, document, or well organized by clearly defined procedures6.

Contingency has different meanings for different estimators and management personnel10,8,26. For example: contractors consider it as a fund for more profit. Consultants count it as a fund to cover: design minor mistakes and / or owner change orders. The owner keeps this fund to address and mitigate unforeseen situations that may occur over project durations26. Risner (2010)15 defined contingency as untapped funds which may generate a high risk for construction
projects in case of misuse. The literature contains different methods for contingency estimation divided into deterministic and probabilistic and lately fuzzy system was used in contingency estimation or a hybrid method between any two approaches (i.e. Monte Carlo and fuzzy system). Traditionally, the most widely used method is “Crystal Ball” method by setting a percentage of total project cost (i.e.: 5% 10% etc…). But this method is arbitrary and difficult to defend. Based on limitations of this method, deterministic methods have been developed for contingency estimation in order to add realistic approach such as: Expected value method, Risk Analysis Method, and Method of Moments. The commonly used probabilistic methods are those using Simulation (i.e., Monte Carlo Simulation). These methods are divided by two categories correlated methods and independent methods (i.e., Pareto Principle or 80/20 rule, PERT, Risk Ranking, etc…), but both categories are difficult to be adopted due to complexity and need of historical data which is not always available. In order to overcome this limitation a new fuzzy-based system methods have been developed. Fuzzy system theory is considered an effective alternative to the random modeling of uncertainty and it doesn’t require any assumption about inputs like PDF shapes, correlations (i.e. Poisson distribution). As to contingency management, the literature indicates that current practice depends largely on project managers rather than systematic and well-structured procedures. As well, management polices remain organization dependent. For example the policies of the department of transportation (DOT) are different from those of, department of energy (DOE) in the USA. Documented progress meetings of projects of these departments show different contingency management procedure followed by Turner (2011), e-builder (2009), Orange County Public Schools (2008), Canadian department of transportation (2009), U.S. Department of Energy (2009), and U.S. Department of Defence (1996). Furthermore, the municipalities’ projects followed different procedures based on experience and municipality regulation such as: Metropolitan of St. Paul (2011), and Palo- Alto (2011).

The different practices in contingency management provide a motivation for researchers to propose a new procedure for contingency management. For example Ford (2002) generalizes and formulates subjective procedures of contingency management based on project managers’ practice and experience. He identifies two types of strategies applied by most project managers: Passive Strategy and Aggressive Strategy (called also Active Strategy). The passive strategy encourages managers to not spend funds too early to manage unforeseen risks and assure project timely completion while aggressive strategy encourages managers to spend funds linearly from an early stage and to perform flexibility in contingency use.

This research focuses on contingency estimation based on fuzzy-set theory and contingency management based on its depletion over project’s durations. The outputs of this research are: a new methodology for contingency depletion project duration and development of a tool for project contingency estimation using fuzzy system coded using VB.net. The evaluation of this tool has been done by comparing its results with results of other methods using the same case studies. Finally a result discussion, recommendations and conclusion are drawn.

BACKGROUND

Elements of fuzzy set theory, developed originally by Zadeh (1965), for modeling uncertainties are summarized below:

Fuzzy number “A” can be represented by an ascending order quadruple \([a_1, a_2, a_3, a_4]\) as shown in Fig. 1. Each fuzzy number defined by a membership function \(\mu_A\) which can be expressed as:

\[
\mu_A(t) = \begin{cases} 
1 & \text{when } a_2 < t < a_3 \\
0 < \text{value} < 1 & \text{when } a_1 < t < a_2 \\
0 & \text{otherwise} 
\end{cases} 
\]

(1)

Also, the classical set theory can be extended to fuzzy set theory. Suppose A \([a_1, a_2, a_3, a_4]\) and B \([b_1, b_2, b_3, b_4]\) are two fuzzy numbers then, the application of set operations such as intersection (Fig. 1) could be expressed as:

\[
\mu_{A \cap B}(t) = \min \{\mu_A(t), \mu_B(t)\} 
\]

(2)

Fig. 1. The Fuzzy-Set operations
Clearly, the relation between $A \setminus B$ and $A \cup B$ should satisfy equation (3):

$$\mu_{A \setminus B} = \mu_A - \mu_{A \cup B}$$

(3)

Furthermore, fuzzy arithmetic operations such as addition could be represented as:

$$A + B = [a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4]$$

(4)

**PROPOSED METHOD**

The proposed method has two components: contingency estimating and contingency depletion and management. The estimating process encompasses the execution of the following operations:

**Fuzzification**

Cost items are represented by fuzzy numbers based on expert judgment. The output of fuzzification is fuzzy estimates $A_{ij}$ for each cost item $A_i$ given by each expert $E_j$.

$$W_{here}, \{i = 1 \ldots n, \ m \text{ is number of experts participated in estimating cost item } A_i$$

**Unifying Inputs**

All inputs will be re-expressed by a trapezoidal fuzzy number. Crisp fuzzy number will be rewritten $[a, a, a, a]$ instead of $[a]$, uniform $[a, a, b, b]$ instead of $[a, b]$ and triangular $[a, b, b, c]$ instead of $[a, b, c]$.

The fuzzy contingency estimation is carried out at cost item, work package and project levels.

At the cost item level, the fuzzy estimate is calculated as average of all fuzzy estimates given by participating experts:

$$A_i = \frac{1}{m} \sum_{j=0}^{m} A_{ij}$$

(5.a)

$$= \frac{1}{m} \left[ \sum_{j=0}^{m} a_{ij} + \sum_{j=0}^{m} b_{ij} + \sum_{j=0}^{m} c_{ij} + \sum_{j=0}^{m} d_{ij} \right]$$

(5.b)

$$= \left[ \frac{1}{m} \sum_{j=0}^{m} a_{ij} + \frac{1}{m} \sum_{j=0}^{m} b_{ij} + \frac{1}{m} \sum_{j=0}^{m} c_{ij} + \frac{1}{m} \sum_{j=0}^{m} d_{ij} \right]$$

(5.c)

For a package that contains $n_i$ items $A_i (i=1 \ldots n_i)$, calculate the sum of all fuzzy estimates of its items:

$$P_k = \sum_{i=1}^{i=n_i} A_i^k$$

(6)

Similarly, for a project that contains $n_p$ packages $P_k (k=1 \ldots n)$ calculate the project range cost estimate as the sum of fuzzy estimates of its packages:

$$C = \sum_{k=0}^{k=n_p} P_k$$

(7)

**Defuzzification**

The commonly used method for defuzzification is the center of area (COA) which could be expressed as:

$$y^* = \int \mu(x) dx$$

$$\int \mu(x) dx$$

Where, $\mu(x)$ = aggregated membership function

$x = output \ variable$

The defuzzification of a fuzzy number can be represented by its expected value (Table 1) and variance:
Several researchers presented methods for calculating expected value and variance of fuzzy number.

Expected value (EV) and variance (V) of a fuzzy number could be calculated as:

$$ EV = b - \frac{1}{2} \int_a^b \mu(x) \, dx + \frac{1}{2} \int_b^c 1 \, dx + \frac{1}{2} \int_c^d \mu(x) \, dx $$

$$ V(X) = EV(X^2) - [EV(X)]^2 $$

<table>
<thead>
<tr>
<th>Fuzzy Number Type</th>
<th>Expected Value Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crisp</td>
<td>a</td>
</tr>
<tr>
<td>Uniform</td>
<td>( \frac{a + b}{2} )</td>
</tr>
<tr>
<td>Triangular</td>
<td>( \frac{a + 2b + c}{4} )</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>( \frac{a + b + c + d}{4} )</td>
</tr>
</tbody>
</table>
### Table 2: Fuzzy Number Variance

<table>
<thead>
<tr>
<th>Fuzzy Number Type</th>
<th>Variance Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crisp</td>
<td>((b-a)^2)</td>
</tr>
<tr>
<td>Uniform</td>
<td>(\frac{(b-a)^2}{12})</td>
</tr>
<tr>
<td>Triangular</td>
<td>(a^2 + b^2 + c^2 - ab - ac - bc)</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>(\frac{(b-a)}{6} \left( \frac{2}{3} (c-b) \right) + \frac{1}{6} \left( \frac{2}{3} (c-b) \right) + \frac{1}{6} \left( \frac{2}{3} (c-b) \right) + \left( \frac{2}{3} (c-b) \right) - EV^2)</td>
</tr>
</tbody>
</table>

#### Uncertainty Modeling

Uncertainty could be represented by introducing several measures and indices. In this paper fuzziness measure, ambiguity measure, possibility measure, fuzzy number quality index (FNQI), and agreement index are incorporated to model the uncertainty associated with fuzzy number.

**Fuzziness Measure**

The fuzziness measure could be expressed as\(^1\):  
\[
F(A) = \int_{-\infty}^{+\infty} (1 - |2\mu_A(x) - 1|) \, dx \tag{11.a}
\]

By solving equation 11.a, fuzziness measure of a trapezoidal fuzzy number formula could be re-written as\(^1\):

\[
F(A) = \frac{(b-a) + (d-c)}{2} \tag{11.b}
\]

**Ambiguity Measure**

The ambiguity measure could be expressed as\(^1\):

\[
AG = \frac{d + 2c - 2b - a}{6} \tag{12}
\]

**Possibility Measure**

The possibility measure (P) of a fuzzy number \(A\) describes the chance of a fuzzy event \(A \in [a,b]\) to occur\(^2\). The possibility measure could be expressed as:

\[
P(A \in [a,b]) = \sup_{x \in [a,b]} \mu_A(x) \tag{13}
\]

**Fuzzy Number Quality Index**

The fuzzy number quality index (FNQI) could be expressed as\(^1\):

\[
FNQI = \frac{W_f \times F(A) + W_{AG} \times AG(A)}{(W_f + W_{AG})} \tag{14}
\]

Where, \(W_f\) and \(W_{AG}\) are the fuzziness and ambiguity weights respectively.

**Agreement Index**

The agreement index (AI) of two fuzzy numbers A and B could be expressed as\(^3\):

\[
AI = \frac{Area(A \cap B)}{Area(A)} \tag{15}
\]

Application of the developed method and the use of its indices and measures will be demonstrated in the numerical example considered in the case study.

As to contingency management, different types of depletion curves (Fig. 2) were reported in the literature. As described below these curves depend largely on organization practice, manager’s management strategy and experience, and project characteristics.

**Linear Depletion**

This is an ideal depletion curve and the easiest to be followed as planned contingency depletion curve. For Example Turner (2011)\(^21\) used it in Mitchell Park Library Community Center project for Palo-Alto City in United States\(^21\).

**Basic Depletion (S-Curve)**

This curve is called “typical depletion”, since it follows the project cost baseline. The contingency drawdown should follow the same curve which is represented by S-curve\(^12\).

**Front-End Loading Depletion**

This depletion curve is more complicated than linear and basic curves since it needs a bit more effort to be applied. It represents aggressive strategy\(^6\) implemented by managers who believe that project start-up is more risky and fuzzy which rationalize earlier contingency depletion\(^11\).

**Back-End Loading Depletion**

This curve is opposite of front-end loading depletion and it represents passive strategy implemented by managers who prefer to keep funds for timely project completion\(^6\).

**Custom Depletion**

This is a newly proposed contingency depletion curve. It could be named also “tailored depletion curve” since it is generated based on periodically estimated / allo-
cated contingency of project. This curve is a project dependent and it assumes within any period that the depleted contingency should be less or equal to estimated contingency for that period. For example, let consider \( d_j \) is one of project milestones (i.e. completion), \( CE_{ij} \) is estimated contingency for cost item “i” over period \( d_j \), and \( CD_{ij} \) is its depleted contingency for the same period. The total estimated and depleted contingency of project could be expressed as:

\[
\sum_{d_j=1}^{n} CE_{ij} \geq \sum_{d_j=1}^{n} CD_{ij} \tag{16}
\]

![Contingency Depletion Curves](https://via.placeholder.com/150)

**Fig. 2. Depletion Curves types**

Based on each company or project manager experience one of the depletion curves could be selected as planned contingency depletion based on several factors affecting depletion. However, affecting factors and selection procedure are beyond scope of this paper.

**CASE STUDY**

The case study considered here is drawn from the literature for a tunneling project for the city of Edmonton “North Edmonton Sanitary Trunk” (NEST) where the city had an initial estimate of $6 million and a maximum allocated budget of $8.8 million by (Shaheen, 2007)\(^{17}\). The results generated by the proposed method is compared to those of Shaheen (2007)\(^{17}\), Monte Carlo Simulation (MCS)\(^{18}\), and PERT as shown in (Table 3).

**Table 3. Comparison of Expected Value Results**

<table>
<thead>
<tr>
<th>Method</th>
<th>EV formula</th>
<th>Project cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Method</td>
<td>( \frac{a + b + c + d}{4} )</td>
<td>$5,456,526</td>
</tr>
<tr>
<td>PERT(^{9})</td>
<td>( \frac{a + 4\left(\frac{b + c}{2}\right) + d}{6} )</td>
<td>$5,352,680</td>
</tr>
<tr>
<td>Proposed by Shaheen ( (2007))(^{17})</td>
<td>( \frac{1}{3(c - b + d - a)^2} \times \frac{1}{(2(c - b)^2 + (b - a)^2)} \times \frac{1}{(d - a) + (d - a)^2) )</td>
<td>$5,548,706</td>
</tr>
<tr>
<td>MCS (500 iterations)(^{17}) based on generated distribution function</td>
<td></td>
<td>$6,059,263</td>
</tr>
</tbody>
</table>

The results shown in (Table 3) illustrate the accuracy of the proposed method in comparison to other methods. The proposed method can determine the possibility of the cost estimate being at a set crisp value (using the possibility measure). This is not possible using the probability theory, which will yield close to zero\(^{7}\). The method can test the vagueness and imprecision of the estimated cost using the AG and F measures\(^{18}\). Also, the method requires one fuzzy iteration only rather than a number of simulations and does not require data as in Monte Carlo simulation to construct the probability density functions associated with the cost items involved in contingency estimating. The measures and indices incorporated in this paper are: 1) fuzziness measure (F), 2) ambiguity measure (AG), 3) possibility measure (P), 4) fuzzy number quality index (FNQI), and 5) agreement index (AI) between the proposed method fuzzy estimation of NEST project “N\(_1\)” and “N\(_2\)” as shown in Table 4.

**Table 4. Calculation of Measures and Indices**

<table>
<thead>
<tr>
<th>Measure / Index</th>
<th>Formula</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuzziness Measure F(A)</td>
<td>( \frac{(b - a) + (d - c)}{2} )</td>
<td>$1,076,555</td>
</tr>
<tr>
<td>Ambiguity Measure AG(A)</td>
<td>( \frac{d + 2c - 2b - a}{6} )</td>
<td>$376,352</td>
</tr>
<tr>
<td>FNQI (( \alpha=\beta=0.5 ))</td>
<td>( \frac{\alpha \times F(A) + \beta \times AG(A)}{\alpha + \beta} )</td>
<td>$726,453</td>
</tr>
<tr>
<td>AI(N(_1), N(_2))</td>
<td>( \frac{Area(N_1 \cap N_2)}{Area(N_1)} )</td>
<td>0.93</td>
</tr>
<tr>
<td>P(Ae[6.0M, 8.8M])</td>
<td>( \sup_{\alpha(a,b)} \mu_4(x) )</td>
<td>0.507</td>
</tr>
</tbody>
</table>

**Table 2. Comparison of Expected Value Results**

<table>
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<td>( \frac{a + 4\left(\frac{b + c}{2}\right) + d}{6} )</td>
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</tr>
<tr>
<td>Proposed by Shaheen ( (2007))(^{17})</td>
<td>( \frac{1}{3(c - b + d - a)^2} \times \frac{1}{(2(c - b)^2 + (b - a)^2)} \times \frac{1}{(d - a) + (d - a)^2) )</td>
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</tr>
<tr>
<td>MCS (500 iterations)(^{17}) based on generated distribution function</td>
<td></td>
<td>$6,059,263</td>
</tr>
</tbody>
</table>
Now we can examine a number of scenarios. As can be seen from (Fig. 3), the possibility of exceeding the allocated budget is 0.0 while the possibility of exceeding the expected value of the project estimated cost is \( P(\Omega \in [5.46M, +\infty]) = 0.84 \) with an agreement index of 0.52. Also, the possibility of having project cost at 6.0 million is \( P(\Omega \in [6M, +\infty]) = 0.49 \). It should be noted here that it would not have been possible to get a meaningful probability value at this cost estimate using the theory of probability.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, contingency estimation using fuzzy set theory was presented as an effective and accurate in comparison to commonly used methods. Using fuzzy set theory overcomes limitations of probabilistic methods and it gives expert ability to express their knowledge based on their experience. The proposed method circumvent the limitations of simulation; not requiring historical data records to construct probability density functions for the cost items involved and not requiring large number of simulations. It also offers a set of indices and measures that address vagueness and imprecision associated with estimated cost at the cost item, work package and project levels, as well as possibility of having project cost at a specific crisp value or within a specified cost range.

The proposed contingency depletion methodology standardizes contingency management practice and offers a flexible unified procedure making use of policies and procedures adopted by companies and project managers based on their gut-feel, management skills, learned lessons, and regulations generated by experience. It proposed tailored contingency depletion curve so as to improve decision making based on contingency depletion performance over project duration. The limitation of this method is the assumption that all risks associated with project are well identified, reliably evaluated, and effectively responded to by risk management plan.

ACKNOWLEDGEMENTS

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References

The Future of Assistive Technologies for Dementia

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Purpose The use of Assistive Technologies (ATs) for residential dementia care is increasing, yet there is a gap between what individuals want, what developers design, and how outcomes are evaluated. Despite widespread acceptance that ATs improve quality of living (QOL), there is relatively little data to support such claims. This article discusses the current state-of-the-art AT-design, its use and assessment in relation to dementia care and projected future trends that can be incorporated into research now.

Method By reviewing a history of ATs used in residential dementia care, incorporating societal and healthcare trends and applying theories of science, a futuristic view of AT-development and use is presented. The theoretical foundation is rooted in phenomenology, universal design, aging in place and gerontechnology. This research is supported by results from a European Commission-funded project where ATs were integrated and tested in real life conditions and evaluated qualitatively and quantitatively by older adults with dementia as well as their formal and informal caregivers.

Results & Discussion The results show the need for future ATs to be more integrated into the environment, combined with ambient and intelligent technologies, the Internet of Things (IoT), and the potential of cloud computing. They will also become more personalized to individual needs and user requirements.

Keywords: Assistive Technology, Quality of Life, dementia, Ambient Intelligence, Internet of Things, gerontechnology

INTRODUCTION

Assistive Technologies (ATs) are often presumed to increase Quality of Life (QOL) and improve health and social care services for many older adults, yet there is inadequate data to support these hypotheses. It appears that, at least in health services provision and clinical research, performance evaluations of the technological devices, services and psychosocial outcomes is becoming a central paradigm in AT development. The evaluations should be built upon the perceived needs and wants of the end users (i.e. user requirements) so that the development, use and evaluation of the ATs have clear social impacts. Some of the primary barriers to this development are in defining parameters and the correlations between QOL domains and care interventions outcomes.

Persons with dementia are the subjects of the research presented here as there is no current cure for dementia and the primary care goal is in maintaining or increasing QOL. They are a particularly interesting population to work with due to the effects of their syndrome. Being a syndrome means that there are groups of characteristic symptoms, rather than a disease process (with the exception of some types of dementia, such as Alzheimer’s Disease). The most common symptoms are a progressive loss of cognitive functioning, including decision making, mathematics, communication, memory and spatial reasoning. However, each person (and those who work with them) experiences it uniquely. This is why it is so highly individualized and this is where knowing the person makes a world of difference in the quality of the care. Any nurse or caregiver can tell you that they adjust to the dementia, noticing changes in the person throughout the day and over longer spans of time. It is common that people with dementia communicate through their behaviors; this may be due to decreasing communication capabilities (i.e. aphasia or apraxia). Caregivers reach a certain quality of care when they are able to interpret behavioral symptoms (e.g. agitation as a reaction to care) and in turn communicate with the person in an appropriate manner. People with dementia are ideal nominees for benefiting from context-aware technologies and, from an engineering standpoint, they are an ideal challenge to design for. The best, currently known method to intuitively and seamlessly change and adapt the environment to the fluctuations of the user is through technologies associated with Ambient Assisted Living (AAL).

The theoretical basis of this article is rooted in phenomenology1,2, aging in place3,4, gerontechnology5 and exponential growth6. Gerontechnology research currently applies four modules of technology impact (prevention and engagement, compensation and assistance, care support and organization, and enhancement and satisfaction) to five elements of activity (health and self-esteem, housing and daily living, mobility and transport, communication and governance, and work and leisure) to relate technology, activity and health and self-esteem7,8. Further research in this area is needed as we are just starting to be able to interpret information on how older adults interact with and perceive (assistive) technol-
ologies. This article gives a forward-thinking perspective on where these technologies and services are headed in residential care with dementia.

**STATE OF THE ART**

A full State of the Art on ATs for dementia care is beyond the boundaries of this article so current high-tech ATs are presented. Low-tech interventions would include grab bars in the bathroom and ergonomic tools, and are not expanded upon in this work. This section ties in current best practices for residential caregiving for dementia to technologies that can achieve the same goals. It is emphasized that the person’s level of need alone does not describe how the ATs are perceived, used or the resulting outcomes. If ATs are disproportionate to the user’s needs, they are less likely to be utilized, which impedes the fulfillment of care goals. This entails assessing the safety, health and care needs to tailor the individualized dementia care plan.

**Assistive Technologies for Dementia**

Gerontechnology concentrates on four classes of technology. Prevention and engagement technologies strive to delay or defer restrictions in functioning and promote user engagement in their environment. This would range from safety features to interactive interfaces. Compensation and assistance technologies are closely related, but are more fine-tuned to adapt to the user, such as increased lighting when reading and robotics-assisted cleaning. Care support may include devices for physical support, such as lifts for caregivers to transfer a person, or organization, like records of medications administered during the day. Finally, enhancement and satisfaction are like the icing on the cake; they provide services that include ambient lighting and music or virtual reality to enhance the enjoyment of activities. Some of the standard high-tech ATs consist of:

- **Communication** (e.g. e-mail, real-time alarms, access to telecare and medical networks and social support networking).
- **Robotics** can perform household maintenance (e.g. vacuum), as a butler (e.g. assistance with bathing or eating) or companionship activities.
- **Home automation technologies** could monitor and ensure home safety features (e.g. fire and smoke alarms, ventilation, sensors for water temperature, power control).
- **Sensors for monitoring, initiating alarms and data collection.** The most common types of AAL sensors are environmental (e.g. motion detection, PIR, water usage, thermostats), radiofrequency transmitters (e.g. RFID tags) and computer-vision (e.g. webcam, user recognition, motion analysis).
  - Radio Frequency Identification (RFID) technology is used to locate items in the home and GPS/GSM for navigation or locating the person outside the home.

The sensors detect and generate alarms through several techniques and activities are usually divided into event-based and clock-based parameters. For example, motion detectors relay if the user has entered the bathroom, signaling a new event. Say the user has turned on the tap 3 times, which the system interprets as hand washing sub-activities. Fuzzy logic and pattern recognition consolidate the data to identify activities and interpret if there has been variance in the normal daily pattern. Furthermore, machine learning allows computer algorithms to automatically improve experience. The basic idea is for the system to learn a function that maps between some inputs (e.g. sensor readings – water tap turned on in bathroom) and some outputs (e.g. categories of human behavior – washing hands or deviation of activity). Additionally, many of the technologies used for dementia care in the home are or can be connected through the Internet. Internet-based services can provide several benefits to the dementia care plan, such as remote access to system data.

**Dementia Care**

Now we can combine the technologies and the best practices for caregiving. A main function of formal caregiving is in assessing when modifications to the care are needed and again if they are proven beneficial. This is under the hypothesis that the best care is provided when the individual symptoms of dementia are understood. The following is from the Alzheimer’s Association manual, “Dementia Care Practice Recommendations for Professionals Working in a Home Setting” (2010). To allow for a transfer of tasks from caregivers to Assistive Technologies, they at least need to characterize the tasks that were previously performed by humans. The Alzheimer’s Association states that the fundamentals of quality in dementia care consist of:

1. The ability to recognize the signs of dementia and behavioral indicators and to detect changes. Through Machine Learning, Smart Home systems that build upon patterns of interaction in the home can be fine tuned to notice changes in behavior (e.g. increased night wandering).

2. Communication with the person with dementia and their family as well as coordination with other care providers. This can be accomplished through mobile devices (e.g. PDA, mobile phones) as well as stationary computers (e.g. email, video conferences); however, this may still be difficult for a person with dementia, particularly those who have little experience with technology use.

3. Apply and assess nonpharmacological methods (i.e. environmental interventions) to the care plan through person-centered techniques. AT
systems can integrate new technologies and functions can be tailored to the personal care management plan. Sensors can gather information on how the services are utilized.

4. Encourage proper nutrition and hydration. Electronic calendars and reminders are some of the most common used technologies, along with ambient lighting features to draw attention to meals. Refrigerators can monitor weight in the contents to evaluate if food is being eaten regularly, and water taps can register how often the tap is used.

5. Medication management. Electronic calendars with reminders and electronic medication dispensing systems are used, but this is more challenging when meds are not in pill form.

6. Manage home safety issues. This has been one of the fastest areas of gerontechnology to develop as electronically detecting and preventing safety issues is a major user requirement for older adults living alone. Gas and water sensors can turn the appliance off if it has been left on for too long. Gait analysis employs motion sensors and accelerometers can predict falls before they occur. Electronic keys and door sensors can accommodate for entry and exit of the home and fall detectors can alert caregivers or emergency personnel when an incident occurs. It is also important to recognize that wandering can serve to keep the person physically active and allow them to express needs or emotions that they otherwise might not be able to communicate (e.g. pain, too much stimulation, desire for more stimulation, need to toilet, anxiety, adjustments to care, etc.). Wandering is really only considered dangerous when the person is alone or incapable of recognizing safety issues (e.g. outdoors alone, risk of disorientation, doesn’t recognize traffic, not appropriately dressed for the season, etc.). GPS/GSM technologies can localize a person if they do go out or would become lost, and notify the proper authorities.

Although the application of these technologies to care practices is sophisticated, there are some important goals for continued development that are imperative to the future of ATs for dementia care. We are still in need of a common system concept to seamlessly integrate devices and service functions through secure networks. The technologies themselves need continued development, particularly intelligent products that aggregate and integrate contextual data to extrapolate situational user requirements. And we also need continued development in how to interpret the outcomes of the care interactions to make meaningful information out of accrued data.

Functioning, Device and Service Classification
One hindrance to the cohesive assessment of ATs with dementia lies in the lack of a standardized ontology. The benefits of having a common language to describe disease, disability and therapeutic outcomes are seen in clinical use (i.e. determining functional ability, goal setting, care plan management, assessing intervention impacts) and policy (i.e. disability evaluation for services provision, anti-discrimination laws, building codes). Several major classification systems are in current use; it is expected that these will be more unified, centralized and integrated into development and evaluation tools in the future. While establishing standardized ontologies in AT and QOL classification is obviously difficult to realize, an agreed ontology will promote the discourse necessary to develop and evaluate the ATs and their outcomes.

The American Psychiatric Association’s Diagnostic and Statistical Manual of Mental Disorders (DSM) assigns a uniform language and evaluation criteria for clinical diagnosis, research and legal use. The coding of the DSM is to be congruent with the coding used in the International Classification of Diseases and Related Health Problems (ICD); however, they are not revised at the same, and discrepancies exist. The ICD is one of the most prominent classification systems used for coding diseases, symptoms, conditions and causes of injuries and diseases. Conducted an international survey of psychiatrists and found that the DSM was considered more valuable in research and the ICD was most used for clinical diagnosis. Additionally, the WHO’s International Classification of Function, Disability and Health (ICF) is a framework that categorizes health-related subjects into bodily structure and functions, and activities and participation. However, the ICF is not adequate to match nor evaluate abilities with technologies alone. The Patient-Reported Outcomes Measurement Information System (PROMIS) group is creating a domain framework that can be used in their computerized system to collect and interpret therapeutic effects that cannot be currently assessed. The PROMIS group and the Patient-Reported Outcome and Quality of Life Instruments Database (PROQOLID) group are both trying to make cohesion of the thousands of items relevant to QOL domains. In PROQOLID, the domains are divided among working groups that focus on their specific domain. This is beneficial in determining the weight of sub-domains, such as anxiety on emotional affect; but it is worrisome that each work-group devises their own strategy to accomplish this.

Work in this area involves engineers, sociologists, gerontechnologists, psychologists, social and health care professionals and citizens (i.e. caregivers and elderly with dementia), so a common language to define and describe the technology must be applica-
ble to several tiers of understanding of technologies and dementia care. Once the language is agreed upon, definitions, goals and indicators will be streamlined and these will bring about social impact. The values of the definitions and outcomes have the power to change the lives of citizens in their understanding, use of and evaluation of the ATs. It is expected that with a greater understanding of these values, they will become part of the public communication. In this way, the end user feedback will more efficiently play a role in the continued development of AT systems and outcomes indicators. It will become easier to distinguish the effects of a behavior (e.g. use of an AT) and, hopefully, how those further affect other behaviors (i.e. QOL). Another area of research would be in reliably incorporating the continued changes in science and technological solutions as they develop. At present, the WHO Family of International Classifications (FIC) Development Committee is pioneering plans towards this end.

Evaluations of Systems and Services

In the field of evaluating ATs, most of the literature is on educational settings (e.g. with learning disabilities) or on people with physical handicaps (e.g. wheelchair users). Understandably, evaluations in these dimensions allow for defined outcomes as indicators (i.e. increased test scores in schools or increased mobility with the wheelchair). Although this seems far from investigating Smart Homes and dementia care, the methodology used can be applied to the development of outcomes indicators in this field. Evaluations in this context are important because if we can assess QOL outcomes, we can also assess AT as a treatment intervention.

Current criticisms in the field are that when reviewing AT outcomes in dementia, no comprehensive conclusions can be drawn as data is not collected or assessed in a unified way, study sample sizes are small, the disease and outcomes are highly individual and the majority of reporting is through descriptive studies. The WHO is working on an International Classification of Health Interventions (ICHI), which will be a tool to statistically report and evaluate the Classification of Health Interventions (ICHI), which is collected through biomedical data (e.g. blood pressure, physical functioning tests). Martin refers to these models of QOL as sQOL (subjective), oQOL (objective) and proposes a new model to investigate, fQOL (functional). The administration and scoring methods are still largely conducted by humans, can be costly and time consuming and are outdated to the mode that services are provided (e.g. pen-and-paper testing of cutting-edge technologies). The increasing interest in developing individualized measures reflects the paradigm that life quality is unique to individuals and thus cannot be adequately assessed with measures that ask every patient the same questions and require the same, preset responses. Personalized systems will essentially need personalized assessments. One strategy would be to have the assessment as a software component of the AT system, a type of software-as-a-service. The authors in discuss a prototype assessment that would have intelligence to adapt to the user, adjusting to how they define and act out what the quality of their life is to them. What's more, collecting information on ATs and QOL outcomes via the Internet allows for meta-analyses involving multiple groups and diverse locations to compare, for example, treatment x versus treatment y. This has remarkable implications for Randomized Controlled Trials (RTCs) in accruing participants for longitudinal and ethnographic studies and how we can ascertain care needs by increased ability and reliability in detecting statistically significant factors. An anticipated cohesion strategy would be to connect the classification systems mentioned above with the home AT system, including the QOL assessment itself.

We have increasing ability to optimize healthcare but the technology is not perfect yet. We haven’t worked out all the bugs in making innovative technology platforms that can seamlessly sense and integrate itself into the context, collect and interpret data and respond intelligently. The implications of achieving this would allow for monitoring and treating in real time, at the point of care. This leads us to look further into the possibilities of Ambient and Artificial Intelligences and their role as ATs for dementia care.

INNOVATION IN TECHNOLOGIES FOR DEMENTIA CARE

In the era of the digital divide, we are just starting to learn how to gather and interpret information on how older adults interact with technologies. The Law of Accelerating Returns implies that with the exponential growth of technology, we realize more effective and efficient ways to do execute activities and achieve knowledge. Even though this is largely correlated with technology, it is not hard to imagine how other elements of life are affected as a result (i.e. health care and socialization). It is expected that future generations will be more familiar with technology; there will be more homogeneity as everyone
has lived their entire lives with the influence of technology. The technology will also become more personalized to individual needs and user requirements and social and health care services will have streamlined electronic records and communication. By then, we will have a better understanding of how humans interact with technology which can help researchers to better distinguish between individual changes (e.g. preferences, needs and mood states). Some projected future trends in technology development discussed here are in anticipation of developments in context awareness, intelligent data processing, Ambient Assisted Living (AAL), robotics, the Internet of Things and Cloud Computing.

An intelligent home will be better equipped to predict and minimize safety hazards in the home as well as contact help when needed. The best way to arbitrate this is by gathering information on user patterns, environmental hazards, assessing the individual’s needs and initiating an action plan to alert when a safety threshold has been breached. Homes in general will have more electronic features, such as keys, window and door locks and sensors. Gait sensors and accelerometers will not only be able to predict falls, but to determine the physiological root and recommend training or rehabilitation (e.g. greater flex of hips to compensate weak ankles)\textsuperscript{12}. Context-aware systems have the capacity to be cognizant of environmental activities and characteristics through networked equipment, such as mobile, pervasive and ubiquitous computing components.

Minimizing interaction required by the user is especially important with dementia as declines in procedural memory hinder the user’s capabilities. Zero Effort Technologies (ZETs) use algorithms to collect, analyze and apply data autonomously and unobtrusively\textsuperscript{30}. Likewise, AAL systems interlink individual components to assist with household and daily activities\textsuperscript{31}. As part of an AAL environment, ZETs could automatically clean surfaces or items, water plants, open and close windows or curtains and perform other functions that ensure safety in the home while maximizing personal privacy and freedom. The applications can extract environmental information (tag the captured data), interpret information (adjust to the dynamic context) and apply large amounts of varied information (execute a function). Intelligent home systems will be able to collect biosignals and physiological data which helps detect behavioral changes as well as interaction fluctuations in the home’s integrated devices or appliances. These will also be able to identify indicators of change in communication or cognition in the user and possibly differentiate them from outcomes of care management or comorbid conditions (e.g. depression, pain). Innovation in smart materials\textsuperscript{32} may mean that textiles such as clothing, bandages and wallpaper can detect if the person has an infection or monitor vital signs and respond appropriately.

Simultaneous to ZET development, there is also expansion in research that promotes user interaction. The work in robotics is a good example of this as there is a strong connection between companionship and caregiving\textsuperscript{35}. In\textsuperscript{34} and\textsuperscript{35}, the authors report that older adults who were involved in testing robotic technologies became socially and emotionally attached to the robots, talking to them, naming them and anticipated missing them when the trials would be over. Borka and SARAH\textsuperscript{36,37} are examples of robotic technologies that perform tasks while providing companionship. SARAH is a virtual presence, so the software (user-perceived personality) can be integrated into other system agents in the home (e.g. tablet, robot, stove). The LIREC group is also striving to make robots more companion-like by observing canine behaviors\textsuperscript{37}. It is envisaged that robots will be able to detect human expressions (facial and body language), adapt accordingly and even mimic them through the interface; Feelix Growing\textsuperscript{38} is working towards this direction. It will be interesting to see how users will build personal relationships with their technologies and how this effects how they shape their environments and define quality over time.

The increase in micro and personal devices (i.e. wearable medical instruments, RFID tags, smart phones) allows for the user to extend context beyond the walls of the home by integrating biomedical, mechanical, electrical and information and communication technologies (ICTs). The increase in the number and capabilities of devices to be connected is one of the central themes in the Internet of Things (IOT); smart devices can communicate with smart homes and smart cities via the Internet\textsuperscript{39}. Wireless communication networks (i.e. cell phone networks, mesh networks, WiFi networks) essentially connect end users with a city’s network to provide assistance in public transportation, medical appointments and socialization activities, for example. This leads us to consider the role that Cloud Computing will play in connecting the Internet of Things for the future of dementia care. Cloud computing is basically a distributed computing model that delivers services over the Internet. Internet-centric software that can be accessed globally, and is scalable for multiple users, platforms and networks is one of the newest models of service delivery. Currently, the services are categorized as Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS)\textsuperscript{10}. Amazon Web Services is the largest public cloud provider; the public services are essentially available to anyone on the Internet. Private cloud services are available to a limited number of vendors behind a firewall, (i.e. US Department of Defense). If
a tenant would use public cloud resources to make their private cloud, they have created the third type of cloud computing, the virtual private cloud. There are also hybrid clouds and mission-critical clouds, and it is expected that these will continue to evolve in the coming years. However, because cloud computing is still quite new, key areas still need to be addressed. A legal framework needs to be in place to protect the privacy of users and to cooperate with international regulations. Technical services also need to reach a point where they are secure and accessible; this involves technical standardization and service level agreements. For more details on research related to Cloud Computing in Europe, please see\textsuperscript{41}.

**DISCUSSION**

Although some strides have been made in assessing AT outcomes with dementia, we are still far from our goals of understanding how end users interact with the technologies and the intricacies of the effects. This article has discussed recent trends in technologies for dementia care. Assistive Technologies alone as well as AT systems have strong potential to positively influence QOL. Context-aware technologies that utilize sensing and machine learning can autonomously perceive the environment, learn from and adapt to the user, and carry out predefined, goal-directed tasks in real-time. Particularly in dementia, they can aid in tasks that require learning and decision making (two of the primary limitations characteristic of dementia). Furthermore, there is potential for communities (Smart Cities) to play a role in the future of living with dementia by connecting the user and their devices (Internet of Things) to services through Cloud Computing. Of course, there are major issues in data storage, system integrity, privacy and security, networked architecture and service provision, but it is worth starting a dialogue on these issues and setting forward-thinking, goal-directed research ambitions for the future of dementia care. We can imagine what the future holds, now we need to create it.

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Tele-operated service robots for household and care

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Purpose Service robots are a relatively new branch of robotics after the successful industry robots and the experimental humanoids. Service robots are supposed to perform tasks that normally are done by humans in particular daily life activities. However they do not have to do it in the same way as humans and neither do they not have to look like a human. Service robots have to operate in environments meant for humans so they have to navigate in environments with unforeseen moving objects and subjects, to mention only one of the challenges. This paper is based on our experience with a tele-operated service robot, named Rose. Tele-operated means that Rose is not completely autonomous but that it is remotely controlled by a human operator. The human operator has the option to control the robot manually or provide indications to carry out complex coordinated procedures (eg. move and grab object). Tele-operated service robots have a wide range of applications, such as in the building industry to carry and place heavy objects, or in the security business. We focused on daily life household tasks. Experiments with Rose were performed in a field lab setting, for the care of elderly people. They need attention several times a day, but in total not more than two hours. This means that one operator can service several homes. This results in a five-fold productivity improvement of care takers. After an introduction on tele-operated service robots, we concisely present the system design of Rose. Then we sketch the field lab experiments and we consider the lessons learned. Based on this information we present some scenarios for the future of tele-operated service robots for caretaking and household tasks. Both the technical and the application aspects will be covered.

Method First, a number of general purpose use cases covering daily household activities such as warming a meal, picking and placing objects, turning on the light etc. were defined. From these use cases, the system architecture of Rose was derived using a construction technique called correctness by construction. This construction technique guarantees deadlock freedom and livelock freedom. The software development was carried out using the popular Robot Operating System (ROS) framework. Four rounds of tests covering all use cases were carried out by nurses from a care organization called Zuid Zorg in Waalre, the Netherlands. In the first three sessions the cockpit was located in a room next to the robot. In the fourth session, the cockpit was located in Veldhoven, another nearby town, while the robot remained in Waalre. Results from each test round were used to improve the software of Rose. Results & Discussion From the results of all test sessions we were able to confirm feasibility in real-life scenarios and increased productivity by an operator while servicing multiple homes. Furthermore, consistency in performance can be achieved by exploiting the robot’s autonomy.

Keywords: service robots, home-care, correctness by construction

INTRODUCTION Over the last years many initiatives have emerged in developing robots for assisted living: Robots that operate in a domestic environment and perform household tasks. For instance Willow Garage has been developing the PR2 Robot (Personal Robot 2) as a research platform to develop domestic applications. In 2010 this robot was successfully deployed at ten universities all over the world and several have been sold. The Fraunhofer Institute has been developing the Care-o-Bot 3. IBM has been developing HERB (Home Exploring Robot Butler). Furthermore, since 2008 the Robocup at Home competition is held each year to push the development of domestic robots.

Most of these research efforts focus on robots that can either deal with any situation they may encoun-
tic tele-operated service robot. As application domain we chose home care. Our robot had to be able to assist elderly and disabled people. A nurse can control the robot from a central location.

In line with our philosophy our initial focus is on building a manually controlled tele-operated robot. After that we add autonomy to make control easier for the operator. Our robot is named ROSE (Remotely Operated SErvice) and was developed in three iterations.

In the first iteration we mounted two robotic arms on the base of an electric wheelchair and made this apparatus wireless controllable. The robot was built within three months and was used to establish the requirements for the later stages of the project. We concluded that the wheelchair was too massive to control efficiently (or autonomously). In the second iteration we made a robot that could be controlled efficiently from a distance using simple interfaces and we added autonomous movement to the robot platform, both by machine vision and a map. This robot was tested in an apartment for elderly. In the third iteration we designed a new robot based on our test experience from the second iteration. This robot features four individually driven and steerable wheels, a lift to reach the upper shelves of a kitchen cabinet and to pick objects from the floor, additional autonomous functionality, and other improved software.

In this paper first we describe what we mean by service robots for care and tele-operated service robots. Second we describe the use cases that our robots had to be able to achieve. These use cases were selected together with home care personnel and the future clients for our robots (elderly and disabled people) and they are a representative set of tasks that a service robot like ours has to be able to perform in the future. Third we describe the user requirements. These were also defined together with the care organization and input from the elderly. Fourth we describe the architecture of our second iteration robot and cockpit. Fifth we describe the results of the tests at the field tests with Rose 1. We round up this paper with our conclusions and future perspectives.

**SERVICE ROBOTS FOR CARE**

The population of elderly is rapidly increasing and the working population is decreasing. Already there are not enough people who are willing to take care of our elderly. Elderly and physically disabled people mostly want to stay at home and keep their independence as long as possible and institutional care is expensive. Recently the European Union launched the European Innovation Partnership on Active and Healthy Ageing (EIPAHA) that has the goal by 2020 to increase by 2 years the average time a person can live at home. For these reasons we believe it is inevitable that domestic robots will become a solution to help the ageing society.

**TELE-OPERATED SERVICE ROBOTS**

A TSR (Tele-operated Service Robot) is a robot that is controlled by a human from a distance, tele-operation, and performs tasks (services) typically in dangerous environments. Tele-operation is probably the oldest form of robotics. Tele-operation enables a person, called operator, to act remotely as if the operator was on the spot, by for instance copying the manipulations of the operator at a distance. An example is the Da Vinci Robot used for medical surgery.

However, in order to compete with a human care giver the TSR system should be able to perform tasks rapidly, which means that the operator should be able to give a simple command to perform a complex task. Therefore a TSR will also require autonomy in task performance. The TSR field differs fundamentally from industry robots. The field of industry robots is mature and the most well-known applications are in the automotive industry. The main difference between an industrial robot and a TSR is that industry robots are operating in a completely controlled environment that is often designed for them. To program them, only the kinematics of the system are important: the control is completely determined by the coordinates of a position of the robot or its arm. For example the robot arm moves fast (often in an optimal way) exactly to a given position. An industry robot can repeatedly perform an arbitrary sequence of complex tasks.

A TSR moves in an unknown and unadapted environment and the operator is not able to give coordinates. For example consider the movement to a door that must be opened: the operator sees the door via a camera on a screen and he has to give a command to move to the door, to grip the door handle, to move that handle downwards and to pull (or push)
the door. This complex task cannot be commanded by providing coordinates. There could be obstacles in the room that were not there when a similar task was performed before, so the same set of instructions cannot be replayed, as is done with industry robots. Therefore the field of TSR differs fundamentally from the more classical field of industry robots.

A TSR consists of a master and a slave component. The slave is in fact the robot that is executing at a distance the commands given by the master. The slave consists of three components: a mobile platform, a set of arms (one, two or even more) each one equipped with a gripper and a vision system. The master, called cockpit, is an integrated set of devices that enables the operator to control the slave. Seen from a different perspective the master is also a robot, but one with a "human in the loop". 

In a basic TSR the operator has to demonstrate the actions to be executed by the service precisely, maybe at a different scale. In advanced TSR the operator has a high-level command language in which he can order a complex task for the service robot with a simple command. Such a command can be given to the slave by means of advanced input devices such as gloves, joysticks with haptic feedback or by voice recognition. An even more advanced TSR is able to learn behavior from past behavior, programming by example, and by operator training which is in fact supervised learning.

USE CASES
The most cumbersome tasks for home care employees are the frequently and simple tasks. For instance opening curtains, preparing fruit, doing dishes, posting letters. Reducing these simple tasks makes the job more attractive. Elderly and disabled most of all want to maintain their independence as much as possible. However, they become dependent on others already for small tasks.

After extensively workshops with both home care employees and elderly we selected a number of representative use cases that both would give a good cross section of the technical possibilities and the wishes of the care employees and elderly/

- Person detection: The robot moves through the apartment and the operator sees where the inhabitants of the apartment are located. This use case allows us to test whether the robot is able to navigate smoothly in a home environment.
- Turning on the light: The robot moves through the apartment and switches on a light. This use case allows us to test whether the robot is able to manipulate buttons in a home environment.
- Moving an obstacle: The robot moves through the environment and moves an obstacle aside. This use case allows us to test whether the robot is able to move objects in its environment using both arms.
- Preparing a set of breakfast items: The robot takes a set of breakfast items and brings them to the client. This use case allows us to test whether robot is able to pick and place a set of different sized and shaped objects.
- Pouring a glass of milk: The robot pours milk from a carton into a mug. This use case allows to test whether the robot is able to handle liquids and perform more precise tasks.
- Preparing a pre-cooked meal: The robot takes a precooked meal, heats it in an ordinary microwave and brings it to the client. This use case allows us to test whether the robot is able to perform even more precise tasks and handle dials and small buttons and synchronous arm movements.

To get a better idea of what the robot had to be able to do we described these use cases in detailed scenarios which were also used for scenario-based testing.

REQUIREMENTS
Based on these scenarios we specified the user requirements for the robot and cockpit.

The most important of these requirements were:
- The robot must be operable in an unadapted home environment. This requirement lead to requirements regarding size, for instance it must fit through a door, task space, for instance it must reach the floor and reach the cup boards, and manoeuvrability, for instance it must be able to move through narrow lanes.
- The robot must be operable by a home care nurse which lead to usability requirements on the cockpit side, for instance to use common interface devices and a simple graphical user interface.
The robot must be safe for its environment and itself.
Whenever automation is possible, the robot must perform tasks autonomously, however the human must always be able to take control of the robot.

These user requirements were then translated into mechanical, electronic, and software requirements and further developed into a system architecture.

**ROSE 1 SYSTEM ARCHITECTURE**
The system architecture of Rose 1 consisted of the mechanical hardware, electronics, software and cockpit.

The main components of Rose 1, which was the robot used for the tests described in this paper further on, are:
- a mobile robotics Pioneer 3DX mobile base;
- two Exact Dynamics iArms;
- a Hokuyo UBG-04LX-F0 laser scanner used for mapping the environment, positioned low at the front of the robot;
- a Videre mini stereo camera used as overview camera and for determining the distance to objects. This camera was later replaced by an Xbox Kinect camera which gave much better performance;
- two Dynamixel AX-12 actuators that formed the neck of the robot on which the overview camera was placed;
- a quad core i5 3.33Ghz computer with 8Gb RAM;
- two spy camera's positioned on the gripper of each iArm; and
- a Wifi Router for communication with the cockpit (locally) or via an access point to the internet and a cockpit on a remote location.

The mobile base was powered by a single 12 Volt acid battery while the rest of the robot was powered by two 12 Volt acid batteries, which placed together provided 24 Volt output. A dedicated power board was built to distribute the different voltages required by the individual components. The arms required 22 Volts each, the computer required 19.6 volt. The neck actuators required 9.6 Volts and the laser scanner and the Xbox Kinect required 12 Volts. The Videre camera was powered directly by the computer through firewire.

The operator cockpit consisted of an ordinary PC with a Trustmaster joystick (no force feedback) for manually moving the robot and a space navigator for manually using the arms.

The graphical user interface showed the image of the overview camera (on the top) and the image of the active arm camera below. Operators could select different objects on the overview image by drawing a rectangle on top of them. On the right side the user interface showed the 2dmap of the environment, continuously updated by the laser scanner and containing a footprint of the robot for navigation. On the left side of the screen, space was reserved for client information and robot status.

Operators were able to move the robot autonomously to a location via the mouse by either clicking a location on the map, drawing a rectangle on the image of the overview camera, or by selecting a preprogrammed location. Operators were able to grab specific objects by drawing a rectangle on the image of the overview camera, over the specific object. They were able to put down the object by drawing a rectangle on the image of the overview camera, over a surface (e.g. a table).

Both Rose and cockpit used the Robot Operating System (ROS)\(^1\) as high level software stack. ROS was developed by Willow Garage as an open-source software framework for robot software. They use ROS for their PR2 robot and over the last couple of years many researchers have been contributing to developing new software for ROS. ROS is a meta operating system in which different blocks of robot software (called nodes) communicate with each other via a publish-subscribe mechanism or via a goal-feedback-result mechanism. The main advantage of ROS is that many software parts are reusable and configurable to any robot. The disadvantage of ROS is performance. Stereo image processing took 85% of one CPU core in our case. Path planning took 45% of one CPU core. For Rose 1 we reused several parts of existing ROS software like the Rosaria platform interface, the navigation stack, laser, Kinect and space navigator nodes. However we also developed several new nodes like our cockpit, neck control, iARM interfaces, tracking the arm gripper with the overview camera and nodes for autonomous pick and place tasks.
In order to guarantee proper communication between ROS nodes we developed a software construction framework in which we modeled the communication between nodes using the formal modeling language Petri Nets. With our framework we can guarantee that a software component inside a network of software components (like ROS) can always finish executing its task. This correctness criterion is achieved by construction and we can simulate and analyze the behavior of the software with software tools like CPN-tools. Specifically we modeled and validated the publish-subscribe mechanism and goal-feedback-result mechanism of ROS.

**EXPERIMENTS**

During the spring of 2011 Rose 1 was extensively tested in an apartment in Waalre, The Netherlands. The apartment was unoccupied but fully decorated as an elderly apartment.

Over the course of 4 iterations, 3 home care employees tested Rose 1. These employees were regular computer users. Each test lasted a couple of hours. Session 1 and Session 3 were preceded by a training session of one morning each.

In the first three sessions the cockpit was located in a room next to the robot. The home care employees did not see the robot, however they did hear the robot. The cockpit and robot communicated with each other through a Wifi network. During the fourth session the cockpit was located in Veldhoven while the robot remained in Waalre. A dedicated optic fiber connection was used to guarantee sufficient bandwidth. From within the apartment Wifi was used to connect with the Robot.

In the first session primarily manual control was tested and we tried to perform the 6 preselected use cases. In the second session we introduced arm control by joystick and autonomy (preliminary) and tracking the gripper with the overview camera. Testing focused on gaining experience in grabbing (different objects) and moving around. For the third sessions the usability of autonomy functions got improved and we introduced warnings by audio. Again testing focused on grabbing and placing. For the fourth session no new functionality was introduced.

After each session each operator had to fill in a questionnaire and grade different usability aspects of Rose 1 and they had to give comments on each of these aspects. During the second through fourth session a time trial was conducted in which the operators had to go to the kitchen and bring an object to the living room table.

The following use cases were performed successfully by each operator: turning on the light; finding a person; moving an object (chair) and parts of the other use cases were performed successfully: opening the fridge; opening the microwave; pouring content from one cup to another (not milk but M&M candy); grabbing a number of breakfast items: jar, milk carton, cup, cutlery (from within the cup), butter, coffee. We were able to swing open a door that was already partially opened. We were not able to use a door handle safely. The reason was that the gripper would slip from the handle due to the forces involved.

We were able to touch the floor but not enough to pick up an object. Besides the camera view was insufficient to pick up an object from the floor. We were able to grab a package of coffee from the first shelf of the upper cupboard in the kitchen. We were able to reach the second shelf but were not able to pick up an object from that shelf.

In later sessions we manipulated different objects at different locations in the house: for instance we picked up a TV remote control from a chair and handed it to a person. We picked up candle holders, candles, small coffee milk cups, and bottles.

**TIME TRIALS**

During Session 2 through Session 4 time trials were conducted. Figure 5 shows the results of the time trials during the second test session. The task consisted of: (1) driving from the hallway to the kitchen; (2) pick up an object from the fridge; (3) drive to the living room table (4) and put down the object. For Operator 1, three time trials were recorded. In the first trial (Man) she used the joystick and space navigator to perform the tasks. For the second and third trial (Auto 1 and Auto 2) she used autonomous commands for picking, placing, and moving. Operator 2 performed two time trials (Auto 1 and Auto 2) The times are indicated in minutes.seconds. Over the course of the trials the end time (ET) got better and better because operators got more practiced and they had easier means (autonomous grab and put) at their disposal.
Using autonomous commands greatly reduced the time needed for the task. Autonomously the robot was able to drive faster to the fridge and the table and it increased the operability of the robot.

**OPERATOR FEEDBACK**

From the first session onward, the operators were very satisfied with manually moving the robot through the house. The 2dmap with the robot footprint were already sufficient to move between door posts. In the first session the operators were not very satisfied with manually operating the arms with the Space Navigator. However in the later sessions the operators gained experience with this device and the Space Navigator was preferred over using the Joy-stick for manual control. Autonomy simplified control of the robot. However, it also took time to learn to efficiently use the autonomous functions.

The biggest problem with perception was to accurately perceive depth. By using a camera on the gripper it was possible to exactly position the gripper in front of an object. However the distance to the object could not be perceived accurately. Both the overview camera and the arm camera needed to be used to get an indication of the gripper position with respect to the object. Other perception issues are that sometimes the arm moved in front of the overview camera and when an object had been picked up, the object blocks the view of the arm camera.

Warnings (about possible dangerous situations) were sometimes confusing and contradicted with the information on screen. Audio Warnings had greater were noticed better than textual warnings and some operators preferred to hear the environment sounds while others did not miss them while operating the robot from Veldhoven. There were also problems with the WiFi network. Grabbing objects manually proved difficult, and whether Rose is able to grab and object depended heavily on the shape of the object and the location of the object.

After each session the operators also graded a number of statements on a scale of 0 to 10 (0 meaning fully disagree, 10 meaning fully agree). The operators graded most aspects of the robot with 'sufficient' (Grades 6 to 8). The Operator satisfaction confirmed the remarks described above. The number of operators (3) was too small to draw any further conclusions based on these grades.

**CONCLUSIONS AND PERSPECTIVES**

Taking the robot out of the lab environment and into the home environment with potential operators greatly helped in getting more insight in what the robot could do and what it should do. It gave us a lot of feedback for our next robot. The operators liked our robot and were enthusiastic about it, and saw a future in home care for the robot. Operating the robot (especially with the map) felt like 'playing a video game'. The operators got used to a device that the ordinarily do not use, a Space Navigator. Perceiving depth information via the cockpit was difficult and it seemed force feedback is required for improving the manual control of the robot, for instance to feel when an object hits the table.

In the spring of 2012 we are testing Rose 2 in Waalre. Rose 2 has a complete new architecture based on our test experiences with Rose 1. Rose 2 is a preproduction prototype that we are looking to develop further in the coming three years by placing several robots in different care organizations and different homes. Hereby we gain further experience and further develop robot Rose to a complete product.

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**References**


Reducing shoulder injuries among construction workers

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Purpose The U.S. Bureau of Labor 2008 report stated that the number of workers aged 65 or older is expected to rise by 36.6% from 2006 to 2016. This rise is expected to accompany a 6.9% decrease in the number of workers between ages 16 to 24 and a slight increase by 2.4% for workers ages 25 to 54. This indicates that the industry will face an aging workforce problem that can affect capacity and productivity if workers' health is not properly monitored. An essential problem for the aging workforce is musculoskeletal disorders (MSDs), specifically work-related musculoskeletal disorders (WMSDs). In 2008, shoulder WMSDs constituted 6.9% of all WMSDs in construction, and this percentage was substantially higher for crafts such as electricians, carpenters, and painters. The main risk factor for shoulder WMSDs is prolonged forceful overhead work. This paper presents a method to monitor shoulder WMSDs risk factor development and to act as an alarm to prevent the disorder from happening.

Method An exoskeleton is being developed that will be worn by a worker to wirelessly track upper-arm motion in 3 dimensions using an array of anisotropic magnetoresistive (AMR) sensors, deployed over workers' upper-arms. The sensory system will be controlled using a microcontroller with the ability to save data on an SD card for post-processing.

Results & Discussion Alwasel et al. measured the angle of the upper-arm to trunk using AMR-sensors in an unpublished thesis. The problem with the use of AMR was the assembly itself since the sensor was not held at the center of joint rotation. However, the device presented here will place AMR-sensors at the center of joint rotation by extending the joint axis of rotation outside the body. This will provide enough data to help assess whether a worker is at risk of developing shoulder injury. This technique will help reduce the number of workers that leave the workforce because of injury, and help maintain a good working environment. This technique will also assist in developing and applying health and safety guidelines to overhead work. Thus, it may ultimately help extend the productive age of the construction workforce.

Keywords: gerontology, safety, robotics

INTRODUCTION

Recently the number of industry, equipment, and tools has increased significantly as a result more workers are joining the workforce everyday to fulfill the increasing demand. The increase in the workforce poses a threat on workers' health, world industry, and insurance companies. The U.S. Bureau of Labor 2008 reported that the number of workers, age 65 or older, is expected to rise in 2016 by 36.6% from what it was in 2006. This rise is expected to accompany a 6.9% decrease in the number of workers between ages 16-24 years, and an increase by 2.4% for workers between ages 25-54 years. The rise indicates that the industry will face an aging workforce problem that can affect capacity and productivity if workers' health is not properly monitored. The report also shows that 29% of all injuries and illnesses, that required days out of work, were diagnosed as musculoskeletal disorders (MSDs). Out of all MSDs reported, 6.9% affected workers' shoulders. This percentage significantly increases for crafts such as painters, carpenters, and electricians because these workers spend significant amount of time working above head level which is often reported as the leading risk factor for Shoulder injuries2,4-9. Many health and safety organizations5-7 attempted solving the uprising problem over the years to reduce the impact on health and industry by: publishing safety manuals and guidelines that explain how to perform ergonomically safe tasks, arranging for seminars and workshops to increase the workers' awareness, and suggesting the redesign of some workstations and tasks to be ergonomically safe for the worker. These attempts focused on decreasing the workers' exposure to MSDs risk factors by educating the individuals. These guidelines, workshops, and seminars were proven theoretically to reduce the rate of injury among workers on the field. However, when deployed in the filed their effect was not seen. There is no drop in the percentage of incidents registered for MSDs. In contrary, the percentage is rising.

270
Many reasons contributed in making these techniques not successful when deployed in the field, for example:

- Workplaces design complexity.
- Workers’ level of education.
- Psychological barriers.
- The cost required for monitoring workers’ behavior throughout the workday.

Therefore, the need for a monitoring method to track the MSDs risk factor and act accordingly to decrease the number of injuries in construction fields is essential. However, this solution has to be consistent with the pace of construction industry by:

- Being costly effective for the industry.
- Being deployable on the field.
- Causing no conflict with workers’ performance.
- Causing no psychological consequences.

In this paper a new method to decrease the shoulder WMSDs is proposed. Since shoulder injury is a major type of WMSDs that affect workers during their work lifetime. This method is going to focus on decreasing the number of injuries affecting workers’ shoulders. Monitoring the risk factors leading to the injury and indicating whether a worker is following the guidelines for ergonomically safe work. Reducing the number of injuries in the field is going to reduce the economic and health impact of the injury on the industry.

Tools vibration, repetitive movement, forceful work, and working with hands above head level were reported as risk factors causing shoulder WMSDs. However, tools’ vibrations along with repetitive movements were not highly associated with the injury. In contrast, working with hands above head level combined with forceful work was strongly associated with the shoulder WMSDs.

Considering that tasks performed in a construction sites often involve engaging the worker with heavy tools/objects, it is fair to rate construction tasks as forceful tasks. Therefore, prolonged elevation of the arm above the head level is variable that leads to shoulder WMSD.

As a result, whenever a method proves its ability to monitor the time spent by a worker in awkward posture (working above head level) the number of injuries can be controlled. Managing the injury can be achieved by changing the type of tasks the worker is performing for a period of time, based on published data, enough for the muscles to regain its original shape and condition.

**METHOD**

The objective of this paper is to provide a real-time tracking device that can be implemented in construction field. Accordingly, managing the MSDs risk factors, and decreasing the number of incidents resulting from the prolonged forceful overhead work.

In an unpublished thesis by Alwasel 2011, multiple sensors have been investigated for their feasibility to be used as the sensing element in tracking workers’ posture in construction sites. Because of its durability, precision, simplicity, size, and cost, KMA200 Philips sensor is the most suitable sensor to be used in tracking workers’ posture in construction sites.

The KMA200 advantages and disadvantages were compared to those of gyroscopes, accelerometers, magnetometers, and ultrasonic sensors. Alwasel 2011 used the anisotropic magneto-resistive sensor (AMR) by placing the sensor in the human axilla and attaching the magnet source to the interior side of the upper arm. Author reported that this arrangement showed reliable qualitative results that can point out whether a worker’s arm is higher or lower than a preset angle; in that case the limit was 90° of arm flexion in sagittal plane. Figure 1 shows how the system performed when implemented on a single participant for several movements.

In figure 1 the participant was asked to wear the device and perform the same motion several times. In each motion the participant was asked to elevate his hands higher than a marker drawn on the wall corresponds to 90° of upper arm to torso angle. The participant repeated the motion 9 times. The line shown at 160° shown in figure 1 corresponds to 90° degree of arm elevation. Because of the way that sensor was mounted with respect to the joint center, this system was not able to directly provide quantitative angles. It rather provided qualitative data showing whether the participant exceeded a certain angle (90°).

The problem of the previous system was that the AMR sensors have to be at center of joint rotation.
This way the sensor would behave like it did when measuring a motor rotation with the sensor held at the center of rotation shown in figure 2.

Fig.2. A 180° motor rotation recorded by the KMA200 sensor where the sensor was held at the center of motor rotation.

Producing such results needs either the sensor or the magnet to be invasive, which makes this solution not feasible. Therefore, this paper is suggesting the extraction of human joint centers outside the human body.

3D motion tracking exoskeleton

This paper will explain the approach to extract the human joint center outside of the human body. This approach involves the design of exoskeleton that will ensure that the sensor is implemented in the center of the joint rotation.

Alwasel 2011 system was able to qualitatively measure the motion only in sagittal plane (2D), which lacks motions in frontal plane and motions that result from combination of movement in frontal and sagittal planes. In contrary, presented exoskeleton will be able to track the motion of the joint in 3D.

The exoskeleton is consisted of multiple linkages and hinges to extract the center of joint rotation outside the human body, thus placing the sensor non-invasively. For the shoulder rotation in sagittal plane (Flexion/Extension), the exoskeleton will have a linkage attached to the upper arm to move with its movement. The end of this linkage shown in figure 3 is a hinge-like joint where the magnetic source will rotate with the upper arm flexion. AMR sensor is held stationary at another linkage that extends from the shoulder area. This arrangement will act like the motor and sensor assembly shown in figure 4.

Fig.3. A hinge-like joint that will be placed at the end of upper arm linkage.

Fig.4. A single motor placed on top of the KMA200 sensor.

The other shoulder rotation (Abduction/Adduction) takes place in the frontal plane. This rotation will be detected using the same arrangement with different positions. There will be a linkage extending from the shoulder area to the upper arm, a sensor will be stationary and the magnet rotates with the upper arm rotation in frontal plane. Combining the two rotations, this exoskeleton will be able to mimic the results obtained from the motor movement except the exoskeleton will be three-dimensional. Figure 5 shows what the extraction of the joint center means.
Fig. 5. Extending the axis of rotation outside the body using external linkage (blue) to be able to mount the sensor and magnet in the joint center noninvasively.

Instrumentation

Two programmable KMA200 angle sensors will be used as the sensing element in the exoskeleton. It requires an electrical control unit (ECU) to control the data flow, a memory to store the data, a power supply, a magnet source to generate the magnetic field lines, and an external case to protect the system and to carry it around. Two-500 gauss off-the-shelf magnets will be used to create the saturation level needed to saturate the internal magnetization of the sensing element.

The ECU uses an 80 pins microcontroller –MCU– (PIC18F87J50) that has the ability to communicate to/and from the sensing element in digital and analog form if needed. Further, the MCU includes a buffer stack that is able to save data temporarily. The power requirement for the MCU is fulfilled using a 9V battery along with a voltage regulator to decrease the voltage to the 5V required by the MCU.

Once sensors and magnets are in their respective positions they describe the relation between a moving frame and a stationary reference frame. As the upper arm moves (rotates) from 0 to 180° the magnetic field lines rotate with the same angle resulting in change in resistance of the permalloy which follows equation 1.

\[
R = R_0 + \Delta R_0 \cdot \cos^2 \alpha \quad (1)
\]

where \(R_0\) and \(\Delta R_0\) are the base resistance and the coefficient of resistance as a function of flux, respectively, and \(\alpha\) is the angle between the magnetic flux lines and the current.10

Data acquisition

The change in orientation of the applied magnetic flux-lines result in change in the internal resistances of the permalloy of the KMA200. This change in resistance is what this sensor use to calculate the angle according to equation (1). The KMA200 has the option of outputting the angle in digital or analog form.

In this exoskeleton the angle will be analog, this signal would be sent to a 16-bit analog to digital (ADC) converter for sampling at 100 sample/s. The output of the ADC would be sent to an SD card for storage.

Discussion

The need for a wireless, reliable, cheap, and easy to use motion tracking system is growing not only for shoulder injuries prevention only but also for many applications for example rehabilitation and sports training. This exoskeleton configuration can be applied to other joints in the human body. With minor changes in the linkage positions, this exoskeleton can measure the flexion/extension angle of elbow, knee, or foot.

There many options in the market currently that can track human motion wirelessly. Most of them use the inertial momentum unit technology (IMU). This technology uses assembly of gyroscopes, accelerometers, and magnetometers to track every segment in real time for every axis to get a three dimensional angle.

The problem with systems that uses the IMU technology such as Xsene MVN is the complexity of mathematical operation that they use to extract the required angle requires a powerful control unit. Usually such systems uses mathematical filters such as Kalman filter to compensate the drift of the gyroscope. They use a model that predicts the rotation based on tri-axial accelerometers and then refresh the gyroscope to cancel the drift. This requires a portable control unit that makes the system bulky. Further, the cost of having an IMU system is not feasible if, for example, it would be used to track motion of multiple workers in a construction site. Also the portability of such systems is limited to a maximum of 150 meters from the control unit.

However, the 3D motion tracking exoskeleton uses a single sensor and does not need any complicate mathematical operations to fuse signals or to correct drift. Also it does not require a powerful control unit as it can be managed with a single microcontroller. The cost of the 3D motion tracking system is less than the IMU systems, as it requires fewer components/sensors and controllers. Therefore, the presented exoskeleton is a good candidate to be used in tracking human body segments wirelessly.

The exoskeleton idea is to extract the joint center of rotation outside the human body. Accordingly magnet and sensor could be implemented in their respective positions. As a result, the exoskeleton will produce quantitative angles that can be used in science for
research where the need for a wireless motion tracking is highly needed. Scientists currently use the motion capturing techniques that uses markers to identify many points over the human body. 3D coordinates for each marker is then calculated by the software based on a preset coordinate system. The drawback of such systems is that they only can be used in pre-designed labs, where the lighting is measured, cameras in their corresponding positions with respect to the human, and there should not be any shiny object in the field. Further, these systems require a direct line of sight between the subject performing a motion and three cameras to record the 3D position of markers. Also, these systems suffer from the movement artifact of the markers on skin. Therefore, researchers cannot use this technique to record motion outside the lab. For example, if analyzing athletic motion, the participant should perform the motion in the lab in order for the scientist to extract the angles needed. The 3D motion tracking exoskeleton can replace these techniques because:

- It does not require a line of sight.
- It does not suffer from the movement artifacts.
- Shiny objects will not affect the results.
- It can be used outside the lab.

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References
Assessing assistive technology outcomes with dementia

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Purpose: This article presents a review of the available evaluation of quality of life (QOL) outcomes as a result of assistive technology (AT) interaction among older adults with cognitive impairment and the further development of an outcome assessment framework specific to this area of research. The framework is based on a previous version first proposed by the authors in 20101 and results derived from working on the ISISEMD-project2,3. Method: A literature review compiled relevant AT-outcomes assessments specific to QOL-results of dementia interventions, describing strengths and weaknesses. Furthermore, during the course of the ISISEMD-trials, issues arose that highlighted the lack of appropriate assessments for evaluating QOL in dementia with AT-interventions. This needed to be addressed in order to further develop the fields of AT-outcomes measurement, QOL-assessment, and dementia care. The original framework, describing the development and application of an electronic QOL-assessment format incorporating the AT-enhanced environment for those with dementia, aims to close the variance between AT-use and AT-outcomes with empirical demonstration. Results & Discussion: Results include: (i) Assessment of current outcomes measurement tools and methods; (ii) Analysis of the issues involved in AT-outcomes measurement; and (iii) Description of the framework and its application for dementia AT-outcomes assessment. There is a significant lack of appropriate measurement tools that examine QOL-outcomes as a result of AT-interaction in dementia care. Through the use of the proposed framework, researchers and clinicians can better determine which ATs will stimulate the desired intervention outcomes as well as measure their effectiveness. This has implications for dementia care, technology development, socioeconomic benefits and policy.

Keywords: aging-in-place, technology outcomes assessment, quality of life, dementia

INTRODUCTION
Research on Quality of Life (QOL) is complex due to the subjective natures of reflection and communicating perceptions involved. This is even more convoluted when the person has dementia and the accompanying decreasing cognitive functioning. Dementia is a syndrome characterized by a progressive decline in memory and cognitive capabilities and is one of the leading causes of institutionalization in older adults. The main focus of treatment and care is on maintaining QOL. One way in which QOL can be influenced is through technology, ranging from an electronic calendar to Smart Homes. QOL is a broad concept yet all of the domains identified as influential on QOL can be affected by technologies in the home, referred to as Assistive Technologies (ATs). If the goal is to maintain or improve QOL, the evaluation tools should address this in an appropriate manner. One of the main issues when integrating ATs into the care plan is determining which technologies and services will achieve the most desirable (QOL) outcomes. This article describes relevant QOL assessment tools that would assess ATs in dementia care – this is with the premise that their goal is to detect fluctuations in QOL as an outcome indicator of the AT. If the technology is the prescription, then a higher QOL is the expected side effect. There will also be other side effects (i.e. a better understanding of how those with dementia perceive and use technologies), but this paper focuses primarily on AT-related QOL outcomes. Specific to that, it aims to reflect the importance of environmental influences on QOL and presents a revision of a QOL evaluation framework specific to ATs for dementia care services. Additionally, some of the lessons learned during European trials with end users are presented to illustrate the need for further AT outcome research and development.

QUALITY OF LIFE ASSESSMENT IN DEMENTIA
QOL is a multidimensional concept that consists of psychological, social, physical, objective and subjective factors in a person’s life. The World Health Organization (WHO) defines QOL as one’s perception about their current status in the perspective of their culture, mores and concerning their aspirations, opportunities and interests4. Although the WHO is the main authority cited for defining QOL, there has been incongruence in how QOL should be defined and discrepancy in the theoretical basis of how that can be measured; this presents obvious issues in determining how to view QOL and effectively assess it. MP Lawton5 recommended a hierarchical view that holds behavioral capabilities and subjective life
quality as central divisions and psychological well-being as the desired outcome. Lawton’s conceptualization of QOL in dementia has thus far been the most prominent influence in the development of disease-specific instruments and many of the tools are modeled after his constructs. Lawton’s work is influential here in that he proposes the environment as a criterion or facilitator to achieve psychological well-being, yet Jonker, et al., report that there is a lack of research that presents a paradigm to explain the underlying correlations between QOL and the domain of home environment.

With the intentions of using AT in the home to increase life quality, the authors recognize several perspectives. One is the subjective experience of the individual whose QOL is being assessed (e.g. the person with dementia), another being objective measures (e.g. biological outcomes, closer related to HRQOL) and finally the subjective perception of the proxy individual (e.g. physician or caregiver). Formerly, researchers thought it was impossible to ask the persons with dementia to accurately rate their QOL due to the nature of cognitive impairment and perceived lack of insight; therefore, proxy ratings of patient QOL were the focus of development. Fortunately, later research has shown that those with dementia can still convey their wishes and desires about their life quality to caregivers and researchers. Current theoretical modeling emphasizes incorporation of the individual view of QOL by directly asking older adults with cognitive impairment what is important to them in life quality and why, which also shifts the theoretical paradigm of QOL towards individual perceptions and desires. Although it proves most beneficial to directly ask the older adult with dementia about their QOL, the proxies bring another dimension to the understanding of the situation and care outcomes; they are certainly not discouraged to give reports of QOL, but they are no longer the primary source of QOL information.

It must also be recognized what the intervention strategy is for the individual user, so as to know what the assessment is intending to evaluate. A compensation strategy will attempt to compensate for physical and cognitive decline (e.g. through medication reminders) while a rehabilitation strategy will appraise the level of functioning an individual successfully regains (e.g. walking the dogs). Particularly in dementia where there can be personality changes or behavioral disruptions, there are also cognitive-behavioral strategies, which attempts to help the older adult and their caregivers reduce stressful situations and behavioral outbursts. It is anticipated that a combination of strategies will be most often used in environmental modifications with dementia to accommodate the individual preferences and idiosyncrasies.

**Main Domains of QOL in Dementia**

This section presents an overview of the primary domains of QOL in persons with dementia, and environment is further discussed in terms of how AT can have an impact. This is a basic, yet complex, step to classify which variables comprise and which change QOL, and is by no means finite. The goal of this section is to provide a better understanding of environmental press and why the home is vital to QOL in older adults with dementia. The domains are based on Lawton’s constructs and research reported on focus groups with older adults with dementia. Please keep in mind that QOL is influenced by many factors but as the scope of this paper is on QOL in relation to ATs for dementia care, i.e. environmental interventions, the dimensions and domains that AT influence in this regard are primarily discussed.

- Affect
- Self-esteem and Self image
- Socialization
- Attachment
- (Physical and Mental) Health
- Enjoyment of (meaningful) Activities
- Security and Personal Privacy
- Being Useful
- Physical Environment and Aesthetics
- Finances
- Spirituality
- Self-determination and Freedom

**A Closer Look at Physical Environment**

When considering ATs as a nonpharmacological intervention for dementia care, it is essential to understand how the home environment affects older adults’ functioning and perception of their life quality. In this way, developers, researchers, clinicians and caregivers are better equipped to identify and implement alterations that will be most beneficial. Presently, the WHO defines ATs as environmental factors in their International Classification of Functioning, Disability and Health (ICF), acknowledging that capabilities occur in the context of milieu. The ICF takes the focus off of a biological cause and places it on the impact, allowing representation of the disability in all contexts, not just from a medical standpoint. As people age, particularly when Aging in Place, it is common for them to become increasingly reliant on their surroundings to offset functional decline. Oldey adults spend a significant amount of time in their homes so a principal research goal has been in determining how home environments can support aging. In the field of gerontology, assessments of environmental factors in go back some forty years, including research on residential aspects of...
private homes, neighborhoods and environmental dimensions, such as safety.

The environmental press theory incorporates an individual’s personal competencies (i.e. cognitive, social, physical and psychological capabilities) and their environmental demands (i.e. support or hindrances when interacting with their surroundings)\textsuperscript{20-33}. This theory explains the person-environment fit which rationalizes that too much or too little challenge for the personal competencies result in adverse effects in response to the environment\textsuperscript{20}, the home would serve best in facilitating equilibrium. Here, the competence-environmental press model\textsuperscript{20,32} is used to analyze the relationship between the home and functional outcomes, emphasizing that each individual person will have optimal combinations between their coping capabilities and environmental factors that will facilitate optimum outcomes. It is a model to derive the best person-environment fit through the viewpoint that the less competent a person is, the more impact the environment will have. In 1939, Lewin presented his equation for behavior to explain how nature and nurture combine to shape a person, thus to better explain the person-environment interaction\textsuperscript{34}:

\[ B = f(P, E) \]

He states that the behaviors are functions of both the person and their environment; this places significance on a transitory context to explain a person’s behavior. Hobfoll’s conservation of resources theory\textsuperscript{35} says that the home and objects are resources that have perceived value based on what they can provide for the individual. Their personality characteristics shape their locus of control, life conditions will alleviate or aggravate stress (e.g. retirement, grandchildren), and socialization aspects function to augment or diminish stress in other resources. The authors in\textsuperscript{35} state that older adults who register the lowest levels of (mental and physical) functioning also register the lowest levels of agreement with their environment and face the greatest challenges in environmental press.

ISISEMD Lessons

When determining the service package of ATs for the individual user, requirements were gathered through caregivers, family members, self-reports and, an Occupational Therapist was specifically employed to evaluate how the home could better fit the person’s capabilities. As none of our end users reported disturbing behavioral expressions, we largely employed the compensation and rehabilitation strategies. Unfortunately, by attempting to understand several variables at once, although valuable information was gathered (i.e. on satisfaction with AT services, physical and cognitive functioning), a controlled delineation of the environmental intervention and QOL outcomes was not possible. Rather, our goal was to detect changes in QOL, but not in QOL limited to environmental factors. Some of the notable outcomes for the end users (n=31) with dementia were:

- 77.42\% felt safer about living in their home
- 64.52\% reported increased QOL
- 51.61\% reported increased independent living
- 90.32\% were satisfied with the ISISEMD services

**REVIEW OF DEMENTIA QOL ASSESSMENTS + AT**

Particularly when working with a person with dementia, it is much easier for care providers to affect QOL than it is for them to affect the course of the disease process, which is highly individual. As mentioned earlier, one of the focus areas in measuring QOL is in assessing the efficacy of treatment; the idea is that if we assess QOL, then we are also a step closer to better assessing AT. This section presents current QOL outcomes measurement tools relevant to ATs for dementia care.

The Cochrane Library Collection supports systematic reviews of health care outcomes; specifically, the Patient Reported Outcomes (PRO) methods group is interested in “health status, quality of life, adherence to treatment recommendations and satisfaction with treatment”\textsuperscript{36}. The Cochrane search for “Alzheimer’s Disease,” “dementia,” “quality of life” and “Health Technology Assessment” resulted in 3 documents. One was on pharmacological interventions, one as a proxy report and the last on neuroimaging techniques. Health and QOL Outcomes (HQLO)\textsuperscript{37} is an open access, peer-reviewed journal that disseminates information on Health-Related QOL. The HQLO search for “technology” and “dementia” resulted in 19 documents, all of which were related to severe dementia, frail elderly, other conditions than dementia and other assessments than straightforward QOL. The Patient-Reported Outcomes and Quality of Life Instruments Database (PROQOLID)\textsuperscript{38} was also searched for “Alzheimer’s Disease” and “dementia,” which resulted in a total of 22 instruments, none of which are administered via computer or in electronic format.

- 7 were designed for caregivers alone, excluding self-reports by person with dementia
- 10 tested other measures than QOL, such as memory or apathy
- The 5 remaining, all modeled after Lawton, include:
  1. QOL-AD – Quality of Life in Alzheimer’s Disease\textsuperscript{11} is a questionnaire answered by the person with dementia and caregiver separately and weight is given to the older adults responses but it is not AT-specific
  2. CBS – Cornell-Brown Scale for Quality of Life in Dementia\textsuperscript{39} is a semi-structured joint interview
with the person with dementia and their caregiver, if discrepancies in responses occur, weight is given to the proxy and it is not AT-specific.

3. D-QOL – Dementia Quality of Life Instrument\(^5\) is an mixed interview and questionnaire self-report but is not AT-specific.

4. DEMQOL – Measurement of Health-Related Quality of Life with Dementia\(^40\) is another interview-based tool that is not specific to AT.

5. QOLAS – Quality of Life Assessment Schedule\(^41\) is also interview-based for the person and their caregiver which can be tailored to fit the individual but is not AT-specific.

- No tools were found to be dementia-specific evaluations of QOL and allow for AT influence.

**Supporting Tools**

- **Impact Assessment**
  - The World Health Organization (WHO) has defined Health Impact Assessments (HIA) as "a combination of procedures, methods and tools by which a policy, programme, or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the health population."\(^42\)
  - Although they tend to focus on broader issues of environmental impacts on health quality and do not yet have collective tools to carry out HIAs, the WHO is working to develop methodologies and tools to measure the impact of health on citizens.
  - The HIA group is closely tied to the International Association for Impact Assessment (IAIA), the leading global network on impact assessments with the goal to develop competencies in forecasting and organizing outcomes of development on QOL\(^43\). They have two relevant sections, on health impact assessments and on social impact assessments. A search for dementia in both returned 0 results; however, a search for "quality of life" returned 2 results in the social impact section, a citation summary and international principles for social impact assessment, mentioning that QOL is one of their core values.
  - The National Institutes of Health’s Patient-Reported Outcomes Measurement Information System (PROMIS)\(^44\) seeks to provide researchers and clinicians with data regarding therapeutic effects that otherwise cannot be found in current assessment tools. It is a computerized adaptive testing system (CAT) for the collection of patient-reported outcomes in health status and social well-being to be used for clinical research and practice\(^45\). The PROMIS group is also striving for a consensus on definitions and domains. It will be interesting to see if and how the mode of administration affects the psychometrics of the instruments; indeed, a system such as this is needed. A search for “quality of life” returned 27 hits but no instruments were available for either dementia or QOL from their assessment database (www.assessmentcenter.net/).
  - The Consortium for Assistive Technology Outcomes Research (CATOR) has recommended outcome measures for ATs and the further improvement of AT outcome indicators\(^46\). A search for “quality of life” returned 2 hits, although no information was found on the website regarding dementia.

- **Intervention Classification**
  - The WHO is additionally working on an International Classification of Health Interventions (ICHI) tool to describe and calculate the distribution and advancement of health interventions\(^47\).

- **Disease and Functioning Classification**
  - The WHO’s Family of International Classifications (FIC) network cooperates with international health information systems in the development, implementation, updating and dissemination of health classifications for statistical analyses\(^48\).
  - The American Psychiatric Association publishes the Diagnostic and Statistical Manual of Mental Disorders (DSM)\(^49\), a manual with a standardized ontology and evaluation methodology for clinical and legal use.
  - The DSM is intended to be compatible with the International Classification of Diseases and Related Health Problems (ICD)\(^50\); however, because revisions are not conducted simultaneously, there are incongruities. The ICD is a well-known classification system for diseases, symptoms and causes.

- **QOL and Assistive Technology**
  - The Psychosocial Impact of Assistive Devices Scale (PAIDS) looks at AT outcomes on QOL in people with functional limitations through three dimensions (competence, ability and self-esteem) but is a generic measure\(^51\). It consists of 26 items and investigates QOL outcomes of AT interaction (including low-technologies), but may not be suitable for people with dementia.
  - The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0)\(^52\) is a similar assessment to measure a device and the service it provides; however, questions like “how satisfied are you with the dimensions of your assistive device,” which may be outside the scope of understanding for persons with dementia.
  - The Assistive Technology Device Predisposition
Assessment (ATD-PA)\textsuperscript{53} consists of too many items (i.e. 63) to be feasible for persons with dementia. The FLAIR QOL assessment\textsuperscript{54-56} is a computerized QOL evaluation format to assess ADL functioning as an indicator of QOL. Although the tools are not designed for use in dementia care nor are specified to AT interventions, very important groundwork has been laid in computerized QOL assessment that can be applied to disease-specific evaluations.

Agree and Freedman\textsuperscript{57} reported findings that AT have greater potential to affect QOL when there are greater levels of functional limitations (e.g. more room for improvement). They developed a measure to exemplify the effects of ATs on older adults (ATQoL); however, this is not dementia-specific.

The Kwaliteit van Zorg (KWAZO)\textsuperscript{58} is a Dutch instrument to evaluate the quality of AT services from the user point of view in 7 questions, but is for general ATs (including dentures, glasses and orthopedic shoes) and is not dementia-specific.

Supporting Studies
As no one sufficient tool was found, additional information was sought out in gerontotechnological studies on AT and QOL outcomes in dementia. Many of the studies look at a combination of the desired variables (ATs in the home, QOL and dementia) and provide valuable insights, but there is lack of cohesion in evaluating the results of AT outcomes. To illustrate, Mann, in\textsuperscript{59}, states that while it can’t be said that utilization of ATs necessarily prevents further decline during the disease course, a lack of ATs can lead to greater decline and higher personal and socioeconomic costs in the long run. Mann\textsuperscript{60} relates home modifications (ATs) to decreasing functional decline; however, Thielke\textsuperscript{61} states that recent meta-analysis reveals there is no precise reporting on ATs impact on individual health status or in care outcomes. In\textsuperscript{52}, Gitlin summarizes research into the outcomes of home modifications in dementia. She finds the Home Environmental Assessment Protocol (HEAP) as an observational tool to assess modification outcomes in home safety, orientation and support of function. Gitlin summarizes that when findings do support functional outcomes, they are often correlated to a particular modification (i.e. directed interventions). Wahl and colleagues found 0 studies that involve dementia-related disorders but report that targeted modifications have a larger impact than general interventions (perhaps as they address a specific design to increase functional ability\textsuperscript{62}. They go on to say that the more involved the home intervention is, the better the perceived improvement is. However, the Mann article\textsuperscript{60} was on frail older adults and the Wahl article\textsuperscript{63} is focused on disability-related outcomes and thus cannot accurately be applied broadly to dementia. Although several studies investigate home modifications and functional outcomes, the Housing Enable\textsuperscript{64} was found to be the only assessment to generate a person-environment index (physical features are rated based on the individual’s capabilities, i.e. the person-environment capacity for access to the home features). Researchers from the Netherlands\textsuperscript{65} have compiled an excellent overview of environmental interventions in dementia care. These are largely related to low-level innovation i.e. removing mirrors or installing grab bars) but do mention some high-level technologies (i.e. infrared motion detection and GPS). They point out that there are plenty of ideas for interventions and design guidelines to achieve defined goals, but we are lacking in studies that evaluate and report the effect of interventions on these goals and on the effect of these goals on QOL. “Guidelines alone are thus not yet a guarantee that all goals are achieved"\textsuperscript{66}p. 271. Ettema et al.\textsuperscript{66} find 1225 publications on QOL and dementia but only 6 applicable tools, 3 of which rely on proxy assessments (the other three are instruments 1-3, above). Hacker\textsuperscript{67} finds over 600 available instruments to evaluate QOL yet significant insufficiencies in resources, data and in a unified conceptualization of QOL. Although her focus is on oncology nursing, not dementia, the data compiled is quite relevant and globally promotes the development and use of computer- and internet-administered QOL assessments. Brandt and colleagues\textsuperscript{68} identified 1739 studies on user-centered outcomes of environmental control systems and Smart Homes, of these, only one involved participants with cognitive impairment (brain injury)\textsuperscript{69} and reported increased QOL with the use of electronic calendars. As with other reviews, they found that no discernible conclusions could be drawn, largely due to lack of unification of data, small sample sizes and the majority being descriptive studies. It is also worth noting that not only is there a lack of proper assessment tools, there is also a lack of a cohesive database where they can all be accessed.

ISISEMD Lessons
When preparing the assessment methodology for the ISISEMD project, there were no computer-administered or electronic versions of QOL for dementia and the normative tools available were mostly non-individualized, tested on smaller sample sizes and not specific to ATs for dementia. Furthermore, administrators of the assessments noted that the way in which the tests were worded sometimes emphasized a sense of deficit and we considered rewording some of the questions to avoid distressing end users. The tools to elicit QOL and caregiver burden in the informal caregivers were also worded in a manner that needed attention. Some of the
caregivers emphasized that they also enjoy their caregiving but noted that the language was depressing and a negative view was inappropriate and limited in scope. As an adjustment, we refer to caregiver burden as caregiving stress.

Because it is not easy to gather appropriate end users with dementia to test and evaluate the AT equipment, when a project is successful in obtaining groups of end users, they try to assess as much about the situation as feasible. This means a trade-off between all the things we may want to measure and how many we can actually measure without taxing the participants or skewing the data. As clinicians and researchers, we could not find a QOL tool that would effectively evaluate the outcomes of using our AT system. In turn, we developed an eclectic mix of tools to elicit the information we were investigating (we did, however, use QUEST 2.0 as a guide when creating our user satisfaction evaluation and the QOL-AD as our primary QOL tool). This means that the QOL+AT assessments are quite specific to this study and have been tested on a small number of older adults. One important drawback from the trials was that the technologies were not optimized before installation. Some of these issues were unforeseen, like a monitor not working, insects that live in one region of the European trials but not others and were drawn to the computer glow and cultural idiosyncrasies of opening windows when cooking. After the small-scale initial pilot, we opted to test the equipment in controlled conditions to avoid stressing end users with false alarms and faulty services. Although our methodology may not be applicable to all AT interventions for dementia care, it has been highly influential in shaping this framework.

**Revisions to the Framework**

Groundwork has been laid in the field of QOL research and several main influential factors have been identified, although this is subject to change with societal, technological and care modifications over time. As social and health care is shifting to computerized collection and storage of data, an increase is also expected in the number of QOL tools modernized from pen and paper format to computerized and internet-based. The initial framework for the iQOL assessment tool is presented in, and proposes the development of an electronic QOL assessment tool to be used by people with dementia. Here, we present some revisions to the areas of domain selection, administration and assessment functions. Although the iQOL framework is not complete, it is believed that disseminating information during and on development will help other researchers and developers in their work towards the same goal.

Table 1. Challenges in ISISEMD trials, related research and projected trends

<table>
<thead>
<tr>
<th>ISISEMD Project Trials</th>
<th>Supplementary Research</th>
<th>Projected Trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issues with AT outcome assessments</td>
<td>Gap in synergy in implementation and evaluation</td>
<td>Devices will be able to gather information on AT use themselves</td>
</tr>
<tr>
<td>Challenges with measuring QOL in dementia care</td>
<td>Lack of appropriate methodology for assessing QOL outcomes as a result of AT interaction</td>
<td>QOL tools will incorporate AT outcomes; integration of electronic assessments</td>
</tr>
<tr>
<td>Successful AT design must incorporate the user's individual requirements</td>
<td>Phenomenological perspectives in residential dementia care plans</td>
<td>Phenomenological perspective in AT incorporation; merging of environmental design and outcome assessments</td>
</tr>
</tbody>
</table>

**QOL Domains in Dementia + AT**

Selecting domains of QOL to be assessed is quite central to the use and interpretation (value) of the derived results. Their definition and selection is a fundamental step, it is also one of the most debated steps, as there is no consensus on how this theoretical and methodological phase should be carried out. The domains are still based on Lawton’s seminal work but considerations are being made for gerontechnology as a dimension in its own right to discern home technologies as influential on QOL. It is expected that these domains will be amended in the future as a subject such as QOL is not static throughout time, cohorts or geographical areas.

**Electronic Assessment**

One of the most important benefits of being Internet-based is the ability to collect data from multiple geographic locations and increased potential participants. The assessment itself can be viewed as adaptive to the functioning capabilities of the person, making the elicitations more individualized. For example, it could detect if the wording of the questions is appropriate for the communication abilities or integrate internal consistency checks by asking the same (or similar) questions to ensure similar responses. When used longitudinally, the QOL assessment is tailored to that person’s pattern of QOL, permitting the user to define what life quality means to them. Being able to individualize the assessment to the user increases the comprehension of their situation and outcomes. This means the assessment is better able to determine which areas of QOL the AT may be impacting; it will be clearer to identify care priorities, set goals and evaluate directed interventions. Furthermore, it alleviates some of the difficulties encountered by the one-on-one modality and human errors in administrating the assessment and
evaluating results. It is hypothesized that this will increase the reliability and internal consistency of the data and remove interviewer bias as a factor. However, the effects of the mode of administration (i.e. computerized versus paper questionnaire) have yet to be explored.

The Standard-Gamble (SG) technique is no longer the only utilities method exercised. Instead, this will become an amalgamation of elicitation incorporating questions, multimedia illustrations, Visual Analogue Scales (VAS), Time Trade-Offs (TTOs), Quality-adjusted Life Years (QALYs), Disability-adjusted Life Years (DALYs), Investigating Choice Experiments for the Preferences of Older People Capability Index (ICECAP-O), among other health utilities, to better personalize the assessment to the user (e.g. their cognitive and communication capabilities). The framework revisions allow for incorporating multi-attribute utilities but further research and development is needed in this area.

The individual end user would be the primary source of information on QOL, but provision will allow information to be obtained through self-reports, proxies and through the data the integrated AT system could collect itself. It would be ideal to have a regulated AT database which would be integrated and updated with iQOL versions so that new ATs could be selected and evaluated. ATs would be registered in a database with a categorization of which domains the AT is connected to. Being able to select which technologies and services that have been implemented into the care routine provides a great deal of data on the functioning of the device as well as the effect on QOL and in achieving care goals. This could connect several international classification systems, like the ones mentioned earlier in the article, as represented in Figure 1.

![Figure 1. Example of anticipated evaluation cohesion](image)

**DISCUSSION AND CONCLUSIONS**

ATs that are developed to achieve wide-ranging goals (i.e. independent living and increased QOL) are becoming more commonplace in dementia research and care and this trend is expected to continue. Having the appropriate design of the home environment for older adults with dementia has tremendous potential to positively affect QOL. In the future, this will be done increasingly through the use of technologies. Two key concepts for successful care are appropriateness and comprehensiveness of services for the end user. Yet a search for appropriate evaluation tools reveals that research in assessing QOL outcomes of AT interaction in dementia is lacking. In fact, there are no appropriate tools to assess Assistive Technology's QOL outcomes in dementia care. As a result, not only may many technologies be inadequately matched with users, but suitable evaluations of the person-(AT) environment fit and resulting outcomes are not well defined, much less available.

In the future, gerontechnology may be incorporated as a dimension in QOL assessments; however, much more research and development is needed in the areas of gerontechnology and more pervasive use is needed by older adults in order to determine the accurate dimensions of ATs influence. The fact is, we know the development of such a framework and assessment tool is necessary, but as a scientific field that is quite young and increasingly interdisciplinary, we are still learning why, in which ways and what influences ATs have on QOL in dementia and how to successfully interpret the results.

**ACKNOWLEDGEMENTS**

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When older adults start and stop to use technologies: Long term study on technology usage, computer attitudes and cognitive abilities of Japanese older adults

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Purpose Technology usage by older adults has been studied statically, in rather short periods such as one specific point in time. In order to understand the nature, causes, and influencing factors of technology usage by older adults, longterm investigations are essential. The purpose of this study was to investigate the adoption and discontinuation of technological products and services by older adults, as well as to clarify relationships among older adults’ computer attitudes, cognitive abilities, and usage changes.

Method Older adult volunteers aged 60 and older, residing in a Tokyo metropolitan area and its suburb participated in this investigation. The total number of participants was 166. A questionnaire probing their technology usage and computer attitudes, which was originally developed by the Center for Research and Education on Aging and Technology Enhancement (CREATE) and then modified by the investigators, was sent to the participants every year between 2003 and 2009. They were asked to complete the questionnaire at their own pace and send it back to the investigators by post. Adoption or discontinuation was identified by comparing the daily usage of technologies listed in the questionnaire for every two consecutive years. An attitudes-toward-computers questionnaire was employed as a part of the questionnaire to assess seven dimensions of participants’ computer attitudes: comfort, self-efficacy, gender equality, control, dehumanization, interest, and utility. The participants were also invited to join into an investigation of cognitive abilities every year. Some of them agreed to participate in the on-site investigation sessions every year. Spatial abilities, associative memory, perceptual speed, and field independence were measured with the sections selected form the kit for factor-referenced cognitive ability tests.

Results & Discussion A series of t-tests and repeated-measures ANOVA were conducted to investigate whether there were significant changes of computer attitudes and cognitive abilities when the adoption or discontinuation of technology products occurred. Preliminary results showed two dimensions of computer attitudes–gender-equality and interest–increased when older adults started to use technology products or services. On the other hand, significant decreases in three areas related to computer attitudes, i.e. interest, utility, and control, were observed when older adults stopped to use technological products. For non-computerized products, no changes on computer attitudes were observed. With regard to cognitive abilities, no consistent patterns were observed. In this investigation on technology usage of older adults over several years, computer attitudes were found to be correlated with dynamic changes in technology usage, in addition to the usage status that has been reported in previous studies. On the other hand, cognitive abilities did not show a clear correlation with usage changes, although this relationship was reported in previous studies.

Keywords: older adults, technology adoption, computer attitudes, cognitive ability

INTRODUCTION Technological advancements have become widespread, and their implementation into products of everyday use is accelerating. Now more and more information and communication technology products and services are appearing in our lives. Especially, in the past 30 years, computer, the Internet and mobile phone prevailed among people of all ages. On the other hand, the world population is growing older. Japan, for example, is estimated that the aging population aged 65 and over will reach 35% in 2050. With the development of technology, older adults start making use of those products inevitably. Although technology has the potential to improve the lives of older adults by increasing their independence in daily life and enhancing communication with their family, older adults are often considered not to be capable of adapting those fast-developed technologies. Therefore, supporting the elderly in making use of new technologies has become increasingly important.

Meanwhile, the process of adoption and discontinuance of a technology for older adults is more complex than it was estimated. When a new technology product is launched, older adults may hesitate to try it. Or even if they ever tried, they may stop using it soon. These might be due to the willingness or ability of older adults to adopt the product. Gradually with the penetration of the product among population, older adults may also be influenced by their friends,
family members, or participation in a training course, and then they may restart using it. On the other hand, however, with the decline of their physical or cognitive abilities, older adults may stop using the product again. It is a dynamic process for older adults to adopt a new technology. In many of previous studies, researchers have not focused on this dynamic process very much and studied technology usage by older people as states, assuming that older adults are the same with younger adults; once they start using a technology, they continue using it. In order to understand the nature, causes, and influencing factors of dynamic changes of technology usage by older adults, long-term investigations are essential.

In this study, therefore, older adults’ dynamic changes of using technology were investigated. In this study dynamic change refers to a specific time point when older adults started or stopped to use a certain technology product. Dynamic changes of using, i.e. adoption or discontinuance of a product were recognized by comparing the participants’ reports of daily usage of technologies for every two consecutive years. One factor likely to influence the dynamic change of technology usage is people’s attitudes towards it. Older adults’ computer attitudes have been studied in relation to computer and other technology products usage. Rogers and her colleagues claimed that when older adults received new information about computer, their attitudes toward computer might increase. Umemuro and Shirokane demonstrated a positive attitude was a reliable predictor of actual computer usage in the long term of one year. However, relationships between attitudes and dynamic changes in usages of technologies have seldom been studied. One reason could be that most of studies were conducted in a rather short period, such as several weeks or a year. It is difficult to observe dynamic changes happen. Therefore, if the data are collected in a longer period such as years, it might become possible to track the dynamic changes in usage of technology products by older adults. Other possible factors that are thought to influence technology usage are cognitive abilities. Cognitive abilities are a multifaceted construct, and considered to change with aging. Findings from Umemuro’s study suggested that some of cognitive abilities are important predictors of computer use. Among cognitive abilities that have been studied, spatial ability, associative memory, perceptual speed, and also a cognitive style of field independence have been reported to relate with the usage and learning of computer skills.

In spatial abilities, there are two different yet similar factors: spatial visualization and spatial orientation. Visualization is the ability to manipulate or transform the image of spatial patterns into other arrangements. Orientation is the ability to perceive spatial patterns or to maintain orientation with respect to objects in space. Spatial orientation requires only mental rotation of the configuration, while visualization requires both rotation and performing serial operations. Pak suggested that spatial ability is important in the performance of computer-based tasks because of menu hierarchies that require users to navigate to the desired information.

Associative memory is the ability to recall one part of a previously learned but otherwise unrelated pair of items when the other part of the pair is presented. This memory involves the storage and retrieval of information from intermediate term memory. Umemuro claimed that associative memory is considered to play an important role in remembering interface presentations and user goals in association with operation procedures.

Perceptual speed involves primarily the temporal parameters of a visual search through a field of specified elements. Perceptual speed is also considered to be important for usage of technologies including computer, because some new technologies such as computers often present large amounts of information to users and also require visuomotor control in their operation.

Field independence appears to be related to the cognitive ability called “flexibility of closure”. It is the ability to hold a given visual percept or configuration in mind so as to dissemble it from other well defined perceptual material. The purpose of this study was to investigate the adoption and discontinuance of technological products and services by older adults for a long term of years. This study also aimed to clarify relationships among older adults’ computer attitudes, cognitive abilities and usage changes. Based on the above arguments, two hypotheses were derived for this study:

Hypothesis 1: if older adults start adopting a technology product, their computer attitudes increase; if older adults stop using a technology product, their computer attitudes decrease.

Hypothesis 2: if older adults start adopting a technology product, their cognitive abilities increase; if older adults stop using a technology product, their cognitive abilities decrease.

**METHOD**

**Participants**

Older adults aged over 60 years old residing in Tokyo metropolitan area and its suburban area in Japan participated in this investigation voluntarily. They participated in this research in response to recruitment advertisements on local newspapers. Total number of participants was 166. Of these, 84 were
male (age: $M = 74.37$, $SD = 4.98$) and 82 were female (age: $M = 72.91$, $SD = 5.98$) in 2009.

Procedure
A questionnaire probing their technology usage and computer attitudes, which was originally developed by the Center for Research and Education on Aging and Technology Enhancement (CREATE) and then modified by the investigators to match the goal of this study, was sent to the participants every year since 2003 until 2009. They were asked to complete the questionnaire with their own paces and then send it back to the investigators. The participants were also invited to participate in on-site investigation of cognitive abilities which was held every year. The number of participants agreed to participate in the investigation varied year to year.

If participants answered the same questionnaire in two consecutive years, it was considered as one valid case. Then, dynamic changes of usage, i.e. adoption or discontinuance of a product were recognized by comparing the daily usage of technologies listed in the questionnaire for every two consecutive years, as shown in Figure 1. There is the case that an older adult frequently started and stopped using a product during 2003 and 2009, then the first time he started and the last time he dropped the product were recognized and other changes in between were removed in the remaining analyses.

![Fig. 1 Definition of dynamic changes](image)

Measurements
Technology usage was assessed by a questionnaire asking participants their daily usage experiences of products and services based on modern technologies. They were: touch screen type automatic teller machine (ATM), car cruise control, car navigation system, mobile phone, computer, computerized catalog in a library, copier, fax, home security system, digital camera, video camera, video game, video player/recorder (VCR), DVD player, DVD recorder, ticket vending machine, answering machine, CD player, microwave oven, self-service gas station and IC card.

Participants’ computer attitudes were investigated using the Attitudes Toward Computers Questionnaire (ATCQ). ATCQ is a 35-item multidimensional scale to assess seven dimensions of participants’ computer attitudes: comfort, self-efficacy, gender-equality, control, dehumanization, interest and utility. Participants responded to items on a five-point Likert scale from 1 (strongly agree) to 5 (strongly disagree).

Cognitive abilities and cognitive style were measured with the sections selected from the Kit for Factor-referenced Cognitive Ability Tests developed by Educational Testing Service. Five test batteries were selected and applied: spatial visualization, spatial orientation, associative memory, perceptual speed and field independence.

RESULTS

**Computer Attitudes**
A series of paired $t$-tests were conducted to investigate whether there were significant differences in computer attitudes between the two consecutive years when usage changes of technology products occurred. The results were summarised in Tables 1 and 2.

As seen in Table 1, older adults’ computer attitudes increased significantly when older adults started to use some technology products or services. For example, older adults’ interest increased significantly after they started using digital camera. When older adults started to use copier and computerized catalog in a library, their gender equality also increased significantly.

On the other hand, significant declines of computer attitudes were observed when older adults stopped to use some technological products (Table 2). When older adults stopped using home security system, their computer attitudes of utility declined significantly. Older adults’ interest toward computer dropped significantly when they stopped using digital camera. Also when they stopped using DVD recorder, their computer attitudes of control declined.

For other technology products, i.e. ATM, car cruise control, car navigation system, mobile phone, computer, fax, video camera, video game, VCR, DVD player, ticket vending machine, answering machine, CD player, microwave oven, self-service gas station and IC card, significant changes in computer attitudes were not observed.
Table 1. Means and standard deviations of computer attitudes when older adults adopted technology products

<table>
<thead>
<tr>
<th>Product</th>
<th>Variable</th>
<th>n</th>
<th>Before adoption</th>
<th>After adoption</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copier</td>
<td>gender equality</td>
<td>10</td>
<td>3.00 0.41</td>
<td>3.26 0.55</td>
<td>-2.41*</td>
</tr>
<tr>
<td>Computerized catalog in a library</td>
<td>gender equality</td>
<td>24</td>
<td>3.08 0.56</td>
<td>3.24 0.53</td>
<td>-2.39*</td>
</tr>
<tr>
<td>Digital camera</td>
<td>interest</td>
<td>28</td>
<td>3.67 0.51</td>
<td>3.84 0.49</td>
<td>-3.06**</td>
</tr>
</tbody>
</table>

Note: *p < 0.05, **p < 0.01

Table 2. Means and standard deviations of computer attitudes when older adults discontinued using technology products

<table>
<thead>
<tr>
<th>Product</th>
<th>Variable</th>
<th>n</th>
<th>Before discontinuance</th>
<th>After discontinuance</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home security system</td>
<td>utility</td>
<td>11</td>
<td>3.76 0.35</td>
<td>3.52 0.32</td>
<td>2.95*</td>
</tr>
<tr>
<td>Digital camera</td>
<td>interest</td>
<td>9</td>
<td>3.64 0.53</td>
<td>3.44 0.58</td>
<td>2.68*</td>
</tr>
<tr>
<td>DVD recorder</td>
<td>control</td>
<td>10</td>
<td>3.90 0.37</td>
<td>3.60 0.31</td>
<td>3.31**</td>
</tr>
</tbody>
</table>

Note: *p < 0.05, **p < 0.01

Cognitive abilities
A series of paired t-tests were also conducted to investigate whether there were significant differences in cognitive abilities between two consecutive years when usage changes of technology products occurred. The results were summarized in Tables 3 and 4.

As seen in Table 3, older adults’ spatial visualization, spatial orientation and field independence declined significantly when older adults started using microwave oven, mobile phone, IC card and ATM. Older adults’ associative memory and perceptual speed increased significantly when they started using copier, IC card and computerized catalog in a library.

On the other hand, as seen in Table 4, when older adults stopped using copier, computerized catalog in library, video player/recorder and ATM, their cognitive abilities such as spatial visualization, spatial orientation and field independence increased significantly. Older adults’ perceptual speed declined when they stopped using CD player.

To summarize the results above, with regard to cognitive abilities, no consistent patterns could be observed when usage changes of technologies occurred.

Tab. 3. Means and standard deviations of cognitive abilities when older adults adopted technology products

<table>
<thead>
<tr>
<th>Product</th>
<th>Variable</th>
<th>n</th>
<th>Before adoption</th>
<th>After adoption</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile phone</td>
<td>spatial orientation</td>
<td>6</td>
<td>14.33 11.89</td>
<td>10.00 12.59</td>
<td>3.08*</td>
</tr>
<tr>
<td>Copier</td>
<td>associative memory</td>
<td>7</td>
<td>21.29 4.65</td>
<td>23.86 6.28</td>
<td>-2.47*</td>
</tr>
<tr>
<td>Microwave oven</td>
<td>spatial visualization</td>
<td>4</td>
<td>9.00 3.19</td>
<td>6.63 3.17</td>
<td>3.45*</td>
</tr>
<tr>
<td>Microwave oven</td>
<td>field independence</td>
<td>4</td>
<td>12.00 8.68</td>
<td>8.50 7.55</td>
<td>5.42*</td>
</tr>
<tr>
<td>Computerized catalog in a library</td>
<td>perceptual speed</td>
<td>8</td>
<td>55.13 6.85</td>
<td>58.50 6.44</td>
<td>-4.47**</td>
</tr>
<tr>
<td>ATM</td>
<td>field independence</td>
<td>5</td>
<td>14.00 4.06</td>
<td>10.90 5.66</td>
<td>3.82*</td>
</tr>
<tr>
<td>IC card</td>
<td>associative memory</td>
<td>12</td>
<td>18.08 5.20</td>
<td>23.00 6.62</td>
<td>-3.34**</td>
</tr>
<tr>
<td>IC card</td>
<td>spatial orientation</td>
<td>12</td>
<td>13.00 11.08</td>
<td>4.92 8.11</td>
<td>3.11*</td>
</tr>
</tbody>
</table>

Note: *p < 0.05, **p < 0.01
### Table 4. Means and standard deviations of cognitive abilities when older adults discontinued technology products

<table>
<thead>
<tr>
<th>Product</th>
<th>Variable</th>
<th>n</th>
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<th>SD M</th>
<th>After discontinuance M</th>
<th>SD M</th>
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</thead>
<tbody>
<tr>
<td>CD player</td>
<td>perceptual speed</td>
<td>16</td>
<td>56.00</td>
<td>9.32</td>
<td>51.88</td>
<td>8.72</td>
<td>2.31*</td>
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<tr>
<td>Copier</td>
<td>spatial visualization</td>
<td>5</td>
<td>3.80</td>
<td>3.72</td>
<td>7.55</td>
<td>3.55</td>
<td>-3.05*</td>
</tr>
<tr>
<td>Computerized catalog in a library</td>
<td>field independence</td>
<td>8</td>
<td>11.84</td>
<td>8.86</td>
<td>15.28</td>
<td>8.60</td>
<td>-2.83*</td>
</tr>
<tr>
<td>Video player/recorder</td>
<td>field independence</td>
<td>15</td>
<td>8.22</td>
<td>6.46</td>
<td>11.72</td>
<td>7.27</td>
<td>-2.85*</td>
</tr>
<tr>
<td>ATM</td>
<td>spatial orientation</td>
<td>5</td>
<td>6.20</td>
<td>7.56</td>
<td>9.60</td>
<td>8.17</td>
<td>-3.47*</td>
</tr>
</tbody>
</table>

Note: *p < 0.05.

### DISCUSSION

This study investigated technology usage changes of older adults over years, and relations of computer attitudes and cognitive abilities with these changes. Computer attitudes were found to have relations with dynamic changes in technology usage, as well as with usage status that has been reported in previous studies. The results confirmed attitudes as major influential factor on technology adoption of older people. Explicitly, the dimensions of gender equality, utility, control and interest were found to have relations with dynamic changes of technology adoption. These results underscore the diversity of attitude changes among different products. Jay and Wills\(^6\) mentioned that self efficacy and comfort are two attitude dimensions targeted by the training program. In this research, dynamic changes were supposed to have occurred in their daily life environment and not necessarily with a help from interventions. This might be the reason that there were no changes observed on these dimensions.

Another important result was that significant changes in computer attitudes were observed only for the computerized technology products; when older people started or stopped to use non-computerized products, there were no significant attitude changes observed. One possible explanation is that the complexity of operation of these two groups of products and services are quite different. Even if some technologies are somehow implemented using computer-based technologies, if older adults don’t have to use complicated commands and menu to control those products, they will not consider them related with computer. Then their computer attitudes might not appear to be significantly different even if they started or stopped to use non-computerized or “somehow computerized” technologies.

Cognitive abilities did not show clear relations with dynamic changes of technology usage, while they have been reported to have some relations with usage status in previous literature. One possible explanation for this could be that cognitive abilities are age-related multifaceted variables, and thus older adults’ cognitive abilities might change regardless of their changes in usage of certain technology products and services. Another point we need to pay attention is that the numbers of valid sample of cognitive abilities were rather small due to the limited number of participants who agreed to participate in the measurement sessions. Thus it is still possible that we could not simply observe any statistically significant results, even if there existed some patterns. The results of this study thus should be interpreted with caution. In order to make this point clear, further investigations with larger sample and longer period should be pursued.

Finally, in this study, all examples of technology products and services were analyzed as a whole and not categorized into groups by nature. As seen in the discussion on non-computerized and computerized products and services in the previous section, some nature of the products could be important in order to better understand the adoption and discontinuance of usage of older adults. Further analysis with this viewpoint should also be pursued in future work.

### References

Alzheimer’s patient activity assessment using different sensors

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Purpose

The number of people requiring care, including Alzheimer patients, will grow while the number of people able to provide care will decrease. We focus on the development of medical, information and communication technologies for improved diagnosis and evaluation of dementia progression in early-stage Alzheimer disease (AD) patients.

Method

We compared several sensors (video and accelerometer) to assess elderly performance on instrumental activities of daily living (IADL) and gait tests in the clinical protocol developed and executed by the Memory Center of the Nice Hospital and the Department of Neurology at National Cheng Kung University Hospital, Taiwan. This clinical protocol defines a set of daily living tasks (e.g., preparing coffee, watching TV), and physical tests (e.g., a balance test), that could be realistic achieved in the designed observation room, and at the same time provide objective information about dementia symptoms. Previous works analyzed only accelerometer sensors for elderly gait analysis for dementia symptoms differentiation, while video-sensors were dedicated to ADL-detection. The comparison of several sensors could provide new evidence about patients’ activities. The proposed systems used a constraint-based ontology to model and detect events based on the sensors data output. 2D-video stream data is converted to 3D-geometric information that is combined with a priori semantic information about the clinical scenario. The ontology language is declarative and intuitive (as it uses natural terms), allowing medical experts to easily define and modify the IADL and gait events models (using spatial, temporal, video-tracking and accelerometers data to describe events). The sensor system has been tested with 44 participants (healthy=21, AD=23). A stride detection algorithm was developed by the Taiwan team for the automatically acquisition of gait information using a triaxial accelerometer embedded in a wearable device. It acquires data about the participant locomotion (e.g., walking time, stride length, stride frequency). It was tested with 33 participants (healthy=17, AD=16), on a 40-meter walking test.

Results & Discussion

This monitoring system detected the full set of activities of the first part of the clinical protocol (e.g., balance test, repeated sequence of sitting-standing positions) with a detection rate of 96.9% to 100% (true positive rate).

Keywords: health & self-esteem, multiple sensors monitoring systems, alzheimer dementia

INTRODUCTION

The older people population is expected to grow dramatically over the next 20 years, and the number of people requiring care will grow accordingly (including Alzheimer’s patients), while the number of people able to provide care will decrease1.

Information and Communications Technologies (ICT) have been proposed to improve and support older people care (e.g., wearable sensors, smart-homes, video monitoring systems). For instance, wearable sensors measurements have been proposed for medical diagnosis trials on the evaluation of older people motor functions2-3. The patients wore a chest or wrist sensor during a gait analysis test to extract kinematic parameters for gait patterns analysis (e.g., stride length, stride cadence). The extracted kinematic parameters were used as evidence to evaluate existing differences between gait patterns of health participants and patient diagnosed with dementia (Alzheimer’s disease patients at mild to moderate stage). Similar ICT applications were applied and studied for the analysis of Parkinson’s disease impairments, e.g., force-plates placed below patient gait test path4 and accelerometer-based wearable devices5. This approach could be also explored for the study of patient activity patterns in activities of daily living (e.g., dressing, eating). Although wearable sensors are suitable for description of personal kinematics parameters, they do not provide data about a subject’s actions over his/her environment.
Video-based system for older people surveillance is growing as a research field (particularly frailty detection)\(^9\)\(^{-13}\), as it can provide data about a person interaction with their environment (e.g., time spent in zones and interaction with objects of interest). Applications are generally associated with detection of daily living activities (e.g., eating, dressing, walking), or the detection of (potentially) dangerous situations (e.g., older people falls). But, for particular domotic environment, illumination conditions, or camera field of view, these systems could have problems in characterizing a person's postures (e.g., bending to an object), or at quantifying an impairment in a limb movement (e.g., a restricted range of motion). Higher resolution video cameras or multiple cameras arrays could be applied in this case, but they will increase the ICT project cost and complexity.

To address the above limitations of current systems, we present the first results of the SWEET-HOME project, an initiative focused on the development of a medical and ICT-based system for the improvement of diagnosis and evaluation of dementia progress in early stage Alzheimer’s Disease (AD) patients.

We attempt to overcome the described limitations of the sole use of video or wearable sensors by deploying several sensors types (video and accelerometer) for our clinical tests analysis. These sensors were tested inside a clinical protocol developed and executed by the Memory Center of the Nice Hospital – France and the Department of Neurology at National Cheng Kung University Hospital – Taiwan.

The clinical protocol is intended to assess older people performance in IADLs (Instrumental Activities of Daily Living, e.g., preparing coffee, watching TV) and in gait analysis tests (e.g., performing a balance test). IADLs are preferred to ADLs, as IADLs have been recently addressed as better indicators of emerging neuropsychiatric symptoms.\(^5\) ADLs generally refer to basic activities of personal self-care (e.g., eating, dressing, washing), while IADLs are associated with more complex tasks, e.g., using the telephone, shopping groceries, organizing medications, and managing personal finances. IADLs seem to be affected earlier than ADLs for early stage Alzheimer patients. We postulate that comparing data from several sensors could provide new (or at least complementary) quantitative evidence about changes in a patient's activities profile.\(^5\) The clinical protocol's activities were specifically chosen according to their possibility of being realistically achieved into the observation room of the hospital and at the same time provide objective information about dementia symptoms.

**MATERIALS AND METHODS**

This multi-centric study was carried out in French and Taiwanese experimental sites. Experiments in France took place in an observation room equipped with household appliances. Experimental data was recorded using a 2D video camera (AXIS®, Model P1346, 8 fps - frames per second), and an ambient audio microphone (Tonsion, Model TM6, Software Audacity, WAV file format, 16bit PCM/16kHz). A motion sensor (e.g., MotionPod®) was fixed on the chest of the participant to quantify their movements. MotionPod® sensor provides an index of activity and estimation about the patient posture (standing, sitting, lying, walking), both of them with a resolution of 1 data per second.

The Taiwanese experiments took place in indoor and outdoor environments. For the indoor experiments a room equipped with household appliances was used and experimental data was recorded using eight ambient 2D video cameras (AXIS, Model 215PTZ, 30 fps). For outdoor experiments a tri-axial accelerometer mounted on the shoes of the participants was used to analyze their gait parameters.

**Clinical protocol**

The Clinical Protocol is divided into four scenarios: directed activities (indoor), semi-directed activities (indoor), undirected activities (indoor), and directed activities (outdoor).

Scenario 01 (S1) or Directed activities in an indoor environment is intended to assess kinematic parameters about the participant’s gait profile (e.g., static and dynamic balance test, walking test). During this scenario an assessor stays with the participant inside the room and asks him/her to perform seven
physical activities within 10 minutes. These activities are briefly described as follows:

- **Balance testing (S1_A1-A4):** The participant should keep balance while performing the following actions:
  - Side by side stand (S1_A1): both feet together,
  - Semi tandem stand (S1_A2): stand with the side of the heel of one foot touching the big toe of the other foot,
  - Tandem stand (S1_A3): stand with the heel of one foot touching the toes of the other foot,
  - Participant stands on one foot (S1_A4): Right foot first then left foot, eyes open, for ten seconds or less if he/she has difficulty.

- **Walking speed test (S1_A5):** The assessor asks the participant to walk through the room, following a straight path from one side of the room to another (chair side to video camera side, outward attempt, 4 meters), and then to return (return attempt, 4 meters);

- **Repeated chair stands testing (S1_A6):** The assessor asks the participant to make the first posture transfer (from sitting to standing posture) without using help of his/her arms. The examiner will then ask the participant to repeat the same action five times in a row.

- **Time Up & Go test (TUG – S1_A7):** Participants start from the sitting position, and at the assessor’s signal he/she needs to stand up, to walk a 3 meters path, to make a U-turn in the center of the room, return and sit down again.

Scenario 02 (S2) or semi-directed activities (indoor) aims at evaluating the degree of independence of the older people by performing IADLs in a given order. The participant stays alone in the room with a list of activities to perform, and he/she has to leave the room only when feeling that has completed the required tasks (no maximum time). It includes 7 indoor IADLs to be performed in the following order:

- Reading for 2 minutes (S2_A1);
- Warming water (S2_A2);
- Making a call for phone number 34775 (S2_A3);
- Watering a plant (S2_A4);
- Watching TV (S2_A5);
- Classifying cards by color (S2_A6);
- Taking ABCD Folder in the zone Office (S2_A7a); Matching ABCD letters of the ABCD Folder with ABCD letters placed over the room (S2_A7b), Returning ABCD folder to its place (S2_A7c), and;
- Leaving the room (S2_A8).

Scenario 03 (S3) or undirected (“free”) activities (30 minutes) aim at assessing how the participant spontaneously initiates activities in the room (e.g., reading magazines/newspapers, drinking, playing cards, and watching TV) and also how he/she organize time without receiving specific instructions. Figure 2 shows the French indoor observation room (Scenarios 1-3).

Scenario 04 (S4) or Directed activities in an outdoor environment aim at analyzing different gait parameters using the tri-axial accelerometers and the stride algorithm developed in the project. The participant is asked to walk around the ring region in the NCKU campus (following the plan shown in Figure 3). During this walking period he/she performs a simple walking test of 40 m on a straight line; and a dual task test where he/she needs to walk the same distance while counting down from 100 to 1.

**Fig. 2. French indoor experimental room, observation room**

**Fig. 3. Taiwanese outdoor experimental environment**

**Participants**

French participants aged more than 65 years were recruited by the Nice Memory Center (NMC) of the Nice Hospital. Inclusion criteria of the AD group were: diagnosis of AD according to NINCDS-ADRDA criteria and a Mini-Mental State Exam (MMSE) score above 15. AD participants with significant motor disturbances as per the Unified Parkinson’s Disease Rating Scale were excluded.

Taiwanese participants aged more than 50 years were recruited by the Department of Neurology at National Cheng Kung University Hospital. The Inclu-
sion criterion of the AD group was a MMSE score value above 16.

Tables 1-4 describe the clinical and demographical characteristics of the participants (healthy control – HC, and AD) according to the different evaluated scenarios.

Table 1. French participants on S1

<table>
<thead>
<tr>
<th></th>
<th>HC (N=21)</th>
<th>AD (N=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, N (%)</td>
<td>12 (50%)</td>
<td>16 (68.75%)</td>
</tr>
<tr>
<td>Age, years (mean ± SD)</td>
<td>73.4±6.09</td>
<td>76.7±7.84</td>
</tr>
<tr>
<td>MMSE (mean ± SD)</td>
<td>28.4±10.98</td>
<td>21.3±3.97</td>
</tr>
</tbody>
</table>

Table 2. French participants on S2

<table>
<thead>
<tr>
<th></th>
<th>HC (N=10)</th>
<th>AD (N=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, N (%)</td>
<td>5 (50%)</td>
<td>11 (68.8%)</td>
</tr>
<tr>
<td>Age, years (mean ± SD)</td>
<td>73.9±6.24</td>
<td>76.7±7.56</td>
</tr>
<tr>
<td>MMSE (mean ± SD)</td>
<td>28.1±1.85</td>
<td>20.7±3.70</td>
</tr>
</tbody>
</table>

Table 3. Taiwanese participants on S1 and S2

<table>
<thead>
<tr>
<th></th>
<th>HC (N=45)</th>
<th>AD (N=36)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, N (%)</td>
<td>24 (53.3%)</td>
<td>21 (58.3%)</td>
</tr>
<tr>
<td>Age, years (mean ± SD)</td>
<td>64.51±8.33</td>
<td>70.25±9.25</td>
</tr>
<tr>
<td>MMSE (mean ± SD)</td>
<td>27.60±2.04</td>
<td>23.44±3.32</td>
</tr>
</tbody>
</table>

Table 4. Taiwanese participants on S4

<table>
<thead>
<tr>
<th></th>
<th>HC (N=17)</th>
<th>AD (N=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, N (%)</td>
<td>9 (52.9%)</td>
<td>9 (56.3%)</td>
</tr>
<tr>
<td>Age, years (mean ± SD)</td>
<td>62.35±2.04</td>
<td>66.69±5.69</td>
</tr>
<tr>
<td>MMSE (mean ± SD)</td>
<td>27.65±2.40</td>
<td>24.19±3.62</td>
</tr>
</tbody>
</table>

Systems overview

Table 5 describes the sensors used to compute different parameters about older people activities (e.g., duration of activity execution, gait parameters).

Table 5. Sensors used for older people activity analysis within each scenario

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Taiwan</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 2D video camera (Activities annotation)</td>
<td>2D video camera (Activities annotation)</td>
<td></td>
</tr>
<tr>
<td>S2 2D video camera (Activities annotation)</td>
<td>2D video camera</td>
<td></td>
</tr>
<tr>
<td>S4 - Tri-axial accelerometer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Automatic Sensor Monitoring System

The proposed automatic sensor monitoring (ASM) system for activity recognition uses a constraint-based ontology to model and detect events based on the sensor data output. 2D video stream data is converted to 3D geometric information, and it is combined with a priori semantic information about the clinical scenario. The ontology language is declarative and intuitive (as it uses natural terminolog-
RESULTS AND DISCUSSION

Results for Scenario 01

French experimental site

Table 7 shows the results of the French participants performing the activities of the Scenario 01. Activity' parameters were calculated using the human expert annotation about the activities in the video sequences. AD participants needed more time to complete the different physical activities due to a lower displacement speed.

| Table 7. French participants' performance for Scenario 01 calculated using annotations of human expert |
|---------------------------------|-----|-----|-----|
|                                | HC  | AD  | p-value |
| S1_A5                          |     |     |        |
| -Walking speed, (Go attempt) (m/s) | 0.88±0.25 | 0.69±0.20 | 0.009 ** |
| -Walking speed (Go back attempt) (m/s) | 1.02±0.21 | 0.77±0.18 | <0.001 ** |
| S1_A6                          |     |     |        |
| -Duration (s)                  | 14.90±5.75 | 19.7±6.79 | 0.012 * |
| -Duration/number of transfers  | 1.50±0.58 | 1.9±0.63 | 0.006 ** |
| S1_A7                          |     |     |        |
| -Duration (s)                  | 10.30±4.12 | 14.6±6.16 | 0.002 ** |

P-values were computed using Student's t-test for the parameters of S1_A5, and by using Wilcoxon Test for the parameters of S1_A6 and S1_A7; (*) Statistical significance at p<0.05; (**) Statistical significance at p<0.01.

The ASM system detects the full set of the guided-activities scenario (e.g., balance test, repeated sequence of sitting-standing positions) using video data with a detection rate from 96.9 % to 100% (true positive rate).

Table 8 shows the same activities parameters of Table 7, but with activity parameters calculated using the activities detected by the ASM system (36/44 video sequences, where HC=16 and AD=20). Although the absolute values of the parameters calculated using ASM results are different from the parameters values obtained from human annotations, the statistically significant differences between healthy participants and AD patients group were preserved.

| Table 8. French participants' performance for Scenario 01 calculated using the ASM system results |
|---------------------------------|-----|-----|-----|
|                                | HC  | AD  | p-value |
| S1_A5                          |     |     |        |
| -Walking speed, (Go attempt) (m/s) | 1.06±0.23 | 0.79±0.23 | 0.001** |
| -Walking speed (Go back attempt) (m/s) | 1.20±0.31 | 0.89±0.23 | 0.002** |
| S1_A6                          |     |     |        |
| -Duration (s)                  | 12.8±5.40 | 17.7±6.31 | 0.006** |
| -Duration/number of transfers  | 1.3±0.53 | 1.7±0.56 | 0.002** |
| S1_A7                          |     |     |        |
| -Duration (s)                  | 8.8±3.80 | 12.1±5.64 | 0.007* |

P-values were computed by using Student's t-test for the on parameters of S1_A5, and using Wilcoxon Test for the parameters of S1_A6 and S1_A7; (*) Statistical significance at p<0.05; (**) Statistical significance at p<0.01.

Taiwanese experimental site

Table 9 shows the results of Taiwanese participants performing Scenario 01. Activity parameters were calculated based on the annotations of Human expert. Activity parameters of Taiwanese participants agree with the French experimental results in the sense that AD participants took more time to perform the selected activities, probably due to their lower speed of displacement when compared to HC participants.

| Table 9. Taiwanese participants' performance for Scenario 01. |
|---------------------------------|-----|-----|-----|
|                                | HC  | AD  | p-value |
| S1_A5                          |     |     |        |
| -Walking speed, (Go attempt) (m/s) | 0.38±0.08 | 0.32±0.07 | 0.001** |
| -Walking speed (Go back attempt) (m/s) | 0.41±0.07 | 0.34±0.08 | <0.001** |
| S1_A6                          |     |     |        |
| -Duration (s)                  | 14.5±3.33 | 20.0±9.41 | 0.001** |
| -Duration/number of transfers  | 1.4±0.33 | 2.00±0.94 | 0.001** |
| S1_A7                          |     |     |        |
| -Duration (s)                  | 10.2±2.42 | 13.4±3.34 | <0.001* |

P-values were computed using Student's t-test for parameters of S1_A5, and using Wilcoxon Test for the parameters of S1_A6 and S1_A7; (*) Statistical significance at p<0.05; (**) Statistical significance at p<0.01.

Figure 6 and 7 show the time taken by the Taiwanese cohort to perform the right and left leg activities of balance test, respectively. Significant differences were found in both tests in the comparison of AD and HC groups (p<0.01 for right leg standing and left leg standing).
Comparison between France and Taiwan results

Figures 8 and 9 show the mean speed of participants in the TUG test for AD and healthy participants at the French and Taiwanese experimental sites, respectively. In both sites, AD patients presented a significantly lower speed compared with healthy controls in the TUG test (p<0.01).

Results for Scenario 02

French experimental site

Tables 10 and 11 present participants performance in Scenario 02 at the French experimental site. Table 10 shows global results according to activity parameters: duration spent inside the room to perform the Scenario 02 (seconds) and organizational errors in activity ordering. Activity ordering errors are presented as the number of participants who at least once omitted, repeated, or changed the expected temporal order of activities.
Table 10. Global performance of the French participants for Scenario 02

<table>
<thead>
<tr>
<th>Activity</th>
<th>HC (Mean±SD)</th>
<th>AD (Mean±SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Total time spent in the room (s)</td>
<td>454±160.4</td>
<td>715±352</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Number of Participants presenting errors about:

- Activity omission (n, %)
  - HC: 0 (0%)
  - AD: 2 (12.5%)
  - p-value: 0.508

- Activity repetition (n, %)
  - HC: 0 (0%)
  - AD: 6 (37.5%)
  - p-value: 0.053

- Activity order (n, %)
  - HC: 0 (0%)
  - AD: 4 (25%)
  - p-value: 0.106

- At least one error at activities organization (n, %)
  - HC: 0 (0%)
  - AD: 8 (50%)
  - p-value: **0.008**

P-values for continuous variables were computed using Wilcoxon test; p-values for categorical variables (2 modalities) were computed using Fisher's exact test; (*) Statistical significance at p<0.05; (**) Statistical significance at p<0.01.

Table 11 shows the participants’ performance for each activity in terms of speed (seconds), omission, and repetition parameters. The speed term was used instead of activity time duration to imply that lower values of this attribute highlight the ability of a participant at performing the activity faster. AD participants spent more time performing activities that involve sorting or classifying objects (A6 and A7), and they had difficulty to manage the time of reading activity (A1) compared to HC participants.

Table 11. French participants performance for each activity of Scenario 02

<table>
<thead>
<tr>
<th>Activity</th>
<th>HC (Mean±SD)</th>
<th>AD (Mean±SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2_A1</td>
<td>138±79.6</td>
<td>88±215.2</td>
<td>0.001 **</td>
</tr>
<tr>
<td>S2_A2</td>
<td>4±3.8</td>
<td>8±13.4</td>
<td>0.660</td>
</tr>
<tr>
<td>S2_A3</td>
<td>25±12.3</td>
<td>28±20.3</td>
<td>0.979</td>
</tr>
<tr>
<td>S2_A4</td>
<td>9±4.4</td>
<td>11±7.2</td>
<td>0.856</td>
</tr>
<tr>
<td>S2_A5</td>
<td>32±23.4</td>
<td>57±57.9</td>
<td>0.165</td>
</tr>
<tr>
<td>S2_A6</td>
<td>78±30.9</td>
<td>143±176</td>
<td>0.216</td>
</tr>
</tbody>
</table>

Taiwanese experimental site

Tables 14 and 15 show the mean and standard deviation of the speed of participants’ activities and their number of errors at performing the activities proposed in the given order (number of activities skipped or performed in a temporal order different from the expected), respectively. Statistically differences were found in the comparison between AD and HC groups (p<0.01, **; p<0.05, *). Activities S2_A4 (water the plant) and S2_A7c ("ABCD" folder) are significant differences between AD and HC for both activity parameters analyzed (speed and frequency).
Table 14. Mean and standard deviation of participants’ speed in activities of Scenario 02

<table>
<thead>
<tr>
<th>Act.</th>
<th>A1</th>
<th>A2 *</th>
<th>A3 **</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>129.8±57.8</td>
<td>41.4±21.0</td>
<td>39.7±22.5</td>
</tr>
<tr>
<td>HC</td>
<td>121.1±49.2</td>
<td>23.8±12.1</td>
<td>21.7±6.9</td>
</tr>
</tbody>
</table>

AD = Alzheimer’s Disease, HC = Healthy Control

Table 15. Mean and standard deviation of participants’ number of errors in the order of activities for Scenario 02

<table>
<thead>
<tr>
<th>Act.</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>0.20±0.41</td>
<td>0.08±0.28</td>
<td>0.08±0.28</td>
</tr>
<tr>
<td>HC</td>
<td>0.26±0.44</td>
<td>0.03±0.18</td>
<td>0±0</td>
</tr>
</tbody>
</table>

AD = Alzheimer’s Disease, HC = Healthy Control

Table 16. Performance of participants for single and dual task of Scenario 04

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Single</th>
<th>Dual</th>
<th>AD</th>
<th>HC</th>
<th>AD</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Times **</td>
<td>34.24±5.24</td>
<td>28.40±3.45</td>
<td>64.03±30.77</td>
<td>37.74±7.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Stride **</td>
<td>32.25±3.36</td>
<td>28.18±2.79</td>
<td>37.81±7.2</td>
<td>28.76±2.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stride Cadence (stride/min)</td>
<td>57.01±4.65</td>
<td>59.87±4.79</td>
<td>39.80±11.34</td>
<td>47.15±8.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stride Length (m) **</td>
<td>1.25±0.12</td>
<td>1.43±0.14</td>
<td>1.09±0.20</td>
<td>1.38±0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stride Frequency (Hz)</td>
<td>0.95±0.06</td>
<td>1.00±0.10</td>
<td>0.75±0.15</td>
<td>0.83±0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stride Speed (m/s) **</td>
<td>1.20±0.18</td>
<td>1.44±0.20</td>
<td>0.83±0.26</td>
<td>1.14±0.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(**: p<0.01)

Results for Scenario 04

Table 16 shows participants performance for single and dual tasks of Scenario 04. AD subjects needed to spend more time and perform more steps than did the healthy controls to complete both 40m walking tests. Furthermore, AD patients presented a significantly shorter stride length and slower stride speed, especially during dual task in the 40m test. In addition, the gait profiles of the AD patients showed lower stride cadence and lower stride frequency compared with those of the healthy controls, but neither phenomena were significant in single and dual tasks.

CONCLUSIONS

Certain similarities are seen between results from the Taiwanese and French sites, although a direct comparison of the results of both sites is not possible due to differences in participant population inclusion criteria. Alzheimer’s patients can be characterized by several criteria according to the clinical protocol scenarios designed in SWEET-HOME project. AD participants presented a lower balance and a shorter gait length frequency, as well as an irregular gait cycle. Similar findings were also found by Gillain et al.2 who pointed out lower gait speed and lower stride length of AD patients when compared to health controls, in single and in dual tasks (gait speed, stride length, stride cycle frequency, and stride regularity).

Alzheimer’s patients have also omitted activities and changed their temporal order indicating a decline in IADLs performance (Scenario 02). Statistically significant differences among AD and HC participants in activity like “watering the plant” could be an indicator of AD participants’ difficulty at performing unusual activities.

The proposed automatic sensor monitoring system (ASM and stride detection) provided activity values similar to the ones calculated from events annotated by a human assessor. Although their absolute values differ, they follow the same tendency, and the statistical differences found among AD and HC groups are preserved (Table 8). These findings highlight the use of the proposed approach as a support platform for clinicians to objectively measure AD patients’ performance in IADLs and gait analysis. Among the advantages of the ASM system are the stability of its results over time (as it does not suffer from emotion-
al state conditions or biases like stress and fatigue), and its quantitative measurement of patient performance.

**FUTURE WORK**

Next developments will focus upon automating the detection of activities in the semi-guided and free scenarios of the clinical protocol using the quantitative measurements as evidence for the automated objective assessment of older people frailty. This extended ASM version will be evaluated at differentiating Alzheimer’s patients at mild to moderate stages from healthy control participants (comparison between AD/MCI and MCI/Control). A multiple sensor data fusion approach will be also studied to enrich patient activity description, and complement patients motor and cognitive ability monitoring.

**References**


Facilitating the adaptability of buildings through the separation of components

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Purpose
Buildings need to be adaptable with relative ease to new user requirements, regulations or technologies. Adaptability reduces the effort and expense involved in adding, changing or replacing building components (such as partitions, doors or plumbing fixtures), throughout the building’s life-cycle. This increases the buildings’ value and sustainability, as well as the building user’s satisfaction. In practice, however, most buildings are designed and constructed to suit their current use, while their future adaptability is ignored. Our research follows an approach that is based on the systematic separation of building components whose replacement occurs at different intervals. Such a separation reduces the efforts, waste and costs currently involved in adapting buildings to the changing needs of their users.

Method
A number of methods are used in order to support the design of adaptable buildings. The building components in the design are ordered through pair-wise comparisons of their replacement rates. This is preferable to an assessment of the actual life expectancies of the components’ in light of the uncertainty regarding external factors such as maintenance policies and future technologies. The relationships between specific building components with different replacement rates are then detected using graph-based methods. A clustering algorithm is applied to a weighted graph representing the design, in order to distinguish between groups of components with different replacement rates. Building components with different replacement rates are then separated through the systematic application of buffers in the building design. A scenario-based method is used to evaluate the costs and benefits of these buffers. A path-search algorithm automatically identifies the components that will be affected by changes in each scenario.

Results & Discussion
Preliminary research included an implementation of the proposed methods in a small-scale case study. Results of this test gave an indication of the feasibility of these methods, suggesting that they might support the design of adaptable buildings. This could facilitate an alternative to current housing policies for elderly people – i.e. adjusting buildings according to the frequently changing needs of their inhabitants, instead of requiring the inhabitants to keep moving as they need more assistance.

Keywords: Management & Social issues, Design Management, Adaptable Buildings, Graph-based Methodology

INTRODUCTION AND RESEARCH OBJECTIVES
Most buildings are constructed at a significant cost and are expected to be functional for many decades to come. For that to happen, buildings have to be adaptable: it should be possible to adjust them with relative ease to the changing needs of their users and to any new regulations or technologies that are introduced subsequent to their construction⁶. Housing for elderly people in particular needs to respond to frequent changes in the users’ needs⁷,²². Adaptability reduces the effort and expense involved in adding, changing or replacing the components of a building throughout its life-cycle. A building component is a product that forms a distinct unit, and has its own functional identity, such as window, a partition wall or a beam. A component may contain a number of different materials, but it is usually constructed or assembled in a single process.

Increasing the adaptability of buildings is one of the most effective ways to increase their value, and their users’ satisfaction²⁰. Non-adaptable buildings are also less sustainable, since they require the demolition and replacement of many components in order to accommodate changes – components that will usually end up in an incinerator or landfill.

In practice, most buildings are, however, designed and constructed to suit their use at that time, and their future adaptability is ignored⁷. Often, the only way to eventually accommodate changes is through extensive and expensive refurbishments. Elderly people, for example, often have to keep moving to new homes as they need more assistance, because their houses cannot be easily adapted to their changing needs.

The objective of this research is to develop a methodology that supports the design of buildings
that can be gradually adapted throughout their use. The methodology is based on the systematic separation of building components whose replacement occurs at different intervals. These components are currently often connected to each other. Connections between components may be physical, such as the connection between one component that is supported or covered by another component, or they may be functional, such as the connection between two components that satisfy the same requirement (Figure 1).

For example, piping with a short physical life may be covered or hidden by tiling with a longer physical life. This may cause waste when the replacement of the piping requires the replacement of the tiling as well. Connections between building components with different replacement rates may cause the owner of a building to refrain from making changes altogether. For example, changes to a heating, ventilation and air-conditioning (HVAC) system may require expensive changes to the structure, because ceiling heights limit the space available for ducts. The separation of frequently replaced piping from the tiling that covers it, or of frequently replaced ducts from the ceiling above them, can facilitate the building's adaptability.

Connections between components may be physical, such as the connection between one component that is supported or covered by another component, or they may be functional, such as the connection between two components that satisfy the same requirement (Figure 1).

Durmisevic and Brouwer have proposed to extend this approach in order to include the separation not only of entire building systems, but also of individual components within a system, which may have different replacement rates. The application of such an approach is particularly challenging in the design of large buildings, which contain thousands of different components that are interconnected through various types of relationships. On the other hand, this approach can be especially effective in such large buildings, when they are built and maintained throughout their lifecycle by the same owners (e.g. hospitals, office buildings, elderly housing, etc.).

In this research, graphs are used to represent the design of buildings. Graphs have been used to model complex systems that consist of many highly interconnected elements. A graph-based representation of projects can facilitate a systematic analysis which takes into account a large number of components simultaneously. Moreover, it allows the use of different graph-theoretic tools and algorithms to partially automate such an analysis – an essential feature when the complexity of the system crosses a certain threshold.

The separation of components can be seen as a form of modularization, i.e., the decomposition of the building into modules. These modules are products that may contain a number of components, and that have carefully designed interfaces with other modules. Modular construction currently focuses on the use of prefabricated three-dimensional modules and two-dimensional panels with certain standard dimensions and interfaces which are repeated throughout the building. The definition of these dimensions and interfaces is based on the requirements of the production, transportation and installation processes of the modules.
The present research, on the other hand, also addresses the functionality of the modules, allowing them to have different dimensions, but not components with different replacement rates. This may facilitate not only the efficient preassembly of the module, but also its efficient replacement. The functionality of the modules is addressed through an analysis of the requirements satisfied by the components in the module. The definition of the requirements in the project brief may thus have an impact on the definition of modules in the design. For example, the requirements in one project may justify the design of a façade panel as a single module which can be easily replaced, while in another project they may justify the design of the panel as an assembly of a number of modules, each of which can be separately replaced.

Attempts to achieve adaptability have, until now, focused on the design of component interfaces that are:

- **Flexible**, allowing components to be easily moved, such as a facade with sliding shutters that can be changed by the user, or reconfigurable sliding walls.
- **Standardized**, allowing one type of component to be easily replaced with another type in a modular system such as a façade or partitioning system.

Buffers in the design can also be used to separate components and contribute to the long-term adaptability of buildings. Buffers can be created through the design of components with a larger capacity. For example, larger service-cores can allow additional pipes and ducts to be installed in the future, without requiring changes to the structure of the service-cores. Other buffers may consist of a larger number of components. For example additional vertical waste pipes can allow new sanitary appliances to be connected in the future without requiring changes to the drainage system.

**Supporting the Design of Adaptable Buildings**

The objective of this research is to develop a methodology that supports the design of adaptable buildings through a systematic separation of building components whose replacement rates differ significantly. The methodology can be used for the detailed design of buildings, once the project brief and the initial design have been defined. It consists of a number of processes (Figure 2):

a. Representation of the building design and project brief as a graph
b. Ordering the building systems according to their relative replacement rates
c. Adjustment of the replacement rates of building components according to requirements in the project brief
d. Separation of components with different replacement rates through the use of buffers and flexible interfaces in the building design

The following sections explain each process in the methodology in more detail:

**Representation of the design and brief as a graph**

In the graph-based representation of the design that was developed in this research, building components are represented as nodes, and the connections between components as links between the nodes. The graph can be created automatically by extracting information from existing object-oriented models of construction projects, such as Building Information Models (BIM). These models contain objects which represent the building components belonging to different systems in the design, as well as information on the physical connections between components.

In order to represent functional connections between components in the graph, the user requirements in the project brief are also represented as nodes. A novel method is used to connect the requirements to building components in the project design, creating one integrated project representation. The nodes in the graph representing the requirements and components are connected through a third type of nodes called design subjects. The design subject nodes have attributes defining the components that satisfy a specific project requirement. For example, a "lighting" design subject links a requirement for a certain level of illumination in a space, with the window and lighting fixture components in that same space (Figure 3).
Graph Transformation (GT) rules can be applied to automatically connect the components and requirements through the design subjects\(^5\). GT is a technique for automatically implementing changes in graphs through predefined rules\(^2\). The GT rules specify how the graph should be built, and how it can evolve. Using GT rules, the model can also be updated according to changes which are proposed for the components in the design.

**Ordering the building systems according to their replacement rates**

In the second stage, building systems in the project's design, or parts of these systems, are ordered according to an initial assessment of their replacement rates. These replacement rates are stored in a generic database, and are based on pair-wise comparisons by experts, rather than on an assessment of the actual size of the life expectancies of the systems.

Replacement rates of building components have been assessed in life-cycle research. However, despite being the subject of numerous studies, life-cycle research has not had much of an impact on practitioners and decision-makers in the construction industry\(^5,16\). An important reason for this is that such research has focused mostly on the physical obsolescence of building components, while their actual replacement rate is more often determined by external factors, such as maintenance policies, changes in the use of a building, new regulations, or the introduction of new technologies\(^17\). These factors are difficult to predict, and there is consequently a general lack of knowledge regarding the actual life expectancy of building components\(^1\).

It may be clear, for example, that the building structure is likely to last longer than engineering services components, and that some of these components will last longer than finishes and fittings, but it can be very difficult to determine the exact number of years they will last. It is therefore more feasible to use an order topology for such an assessment, instead of a metric topology. In other words, it is possible to assess which system is likely to be replaced sooner, even when it is difficult to assess when exactly this will happen.

The assessed relative replacement rates are defined as attributes of the building components, according to the systems to which they belong (Figure 4). Components are often connected in the design to other components that belong to different systems, and which therefore have different replacement rates. The representation of the components as nodes in a graph, with attributes defining their relative replacement rates, allows an identification of the similarity or difference between the replacement rates of any two connected components.
Adjustment of replacement rates of the components

The initial assessment of the replacement rates of the components is based on their expected physical obsolescence rates, and on typical maintenance policies and changes in use. However, the functional requirements in a specific project may cause the replacement rates to be different. For example, the expected tenant turnover in a project may have a significant impact on the replacement rate of certain components. The implications of different scenarios for future changes to the requirements are therefore identified and analyzed by the project team. The components that satisfy a requirement that could change in the future, and which will therefore be affected by this change, can be identified in the graph. This can be done automatically using a path search algorithm that traces the links that connect the project requirements to the components.

The replacement rates of the affected components are adjusted when changes are expected to occur sooner than the assessed replacement rate of the building system to which they belong. For example, if a future change in a requirement will lead to the replacement of a component before it is physically obsolete, its replacement rate is adjusted accordingly. The adjusted replacement rates often do not conform to the preconceived decomposition of the project into systems. Thus, components which belong to different systems, but are affected by the same change, will have the same replacement rates.

Separation of components with different replacement rates

Following the adjustment of the replacement rates of the components, groups of components with similar replacement rates can be identified. These groups are represented by clusters of nodes in the graph that have the same attributes. The identification of the clusters of nodes in a graph can be automated through the use of graph clustering algorithms. Connections between components in different groups can thus be identified. The existence of such connections indicates that changes to components with high replacement rates may require otherwise unnecessary changes to components with lower replacement rates. The objective in this stage is therefore to systematically reduce the dependencies between components with different replacement rates, which are represented by the links between clusters of nodes in the graph. This will allow the building to be more easily adapted at some point in the future.

Groups of building components with different replacement rates are separated through a systematic provision of buffers in the building design, and through the design of modules with standard and flexible interfaces:

a. Buffers are applied to the attributes of components, such as size or number, to reduce the dependency between components and absorb the impact of changes. For example, certain components in the building structure can be designed to withstand larger loads than currently required, in order to be able to accommodate future changes or additions of other building components.

b. Standard interfaces are designed to enable a flexible connection between modules which contain components with different replacement rates. For example, a separation of piping from walls through flexible connections can allow the replacement of pipes without damaging the wall.

Naturally, the choice between introducing either buffers or flexible connections in the design has to be based on an economic evaluation of the cost of each solution.

ILLUSTRATIVE CASE

In order to investigate the feasibility of the proposed methodology, a simple illustrative case of a one-bedroom apartment for an elderly couple, which contains one bathroom, is used. Building
The systems in the apartment are ordered according to their assessed replacement rates:

i. Structure
ii. Exterior walls
iii. Windows and exterior cladding
iv. Interior partitioning
v. Plumbing

The replacement rates of the building components in the design are defined according to the systems to which they belong (e.g. "1" for components belonging to the building structure). The design of the apartment is represented as a graph, in which each building component is represented as a node. Figure 5 shows four of the components, with their replacement rates.

In the next stage, these replacement rates are adjusted by identifying user requirements in the project brief that will likely change in the future. In this case, possible changes in the requirements for the bathroom are identified. Ensuring access and safety for the users as they grow older may require adaptations to the bathroom. Two changes to the requirements are examined:

a. A bathtub is replaced with a shower.
b. The accessibility of the bathroom is improved.

The components that will be affected by these changes are identified by tracing links in the graph-based model that connect the changed requirements to the affected components. Other components, which are physically connected to the components directly affected by the changes, can also be identified by tracing links between the nodes in the graph. Thus, replacing the bath with a shower will also require changing the piping in a wall inside the bathroom, as well as changing the type of window next to the shower. Making the bathroom accessible will require moving a partition wall with the piping inside it, as well as a window next to that wall.

The relative replacement rates of the affected components are adjusted by examining whether the changes in the requirements are expected to occur sooner than the previously assessed replacement rates of the building systems. In this case, the changes are expected to occur sooner than the date at which the plumbing would otherwise have to be replaced. In other words, all the affected components will be changed sooner than their usual replacement rates require. The replacement rate attribute of these components is therefore changed to "6" (Figure 5).

Once the replacement rates have been adjusted, the nodes in the graph are grouped accordingly. Critical links between groups of components with different replacement rates are then identified. These include, for example, links between a window or a pipe that will have to be changed, and other adjacent components whose replacement is not required. The critical links are adjusted to reduce such dependencies, through the design of the interfaces of the components, and through the use of buffers:

a. In the case in which the bathtub is replaced by a shower, the interfaces of components can be designed to allow the expected changes. Thus, the partition wall can be designed to have a demountable covering, so that the piping that

![Diagram](image-url)
runs through it can be changed without damaging the tiling on the wall. The window can be designed so that it can be changed without removing the entire window unit, keeping the frame and the tiling around it intact. In other words, both partition wall and window are not treated as a single module, but rather as a set of components with different replacement rates.

b. In the case of the change in which accessibility of the bathroom is improved, other solutions can be applied. One solution is to design a partition wall as a single module that can be easily demounted and moved, together with the tiling on the wall and the piping within it (Figure 5b). Similarly, the window and adjacent sections of the exterior wall can be designed as modules with interfaces that allow them to be easily changed, without it affecting the building structure. An alternative solution is based on the use of a buffer: an increase in the current size of the bathroom. The choice between installing modular walls and increasing the size of the bathroom has to be based on an economic evaluation of the cost of each solution. Naturally, additional solutions can be proposed which contain both buffers and modules with standard interfaces.

CONCLUSIONS
This paper presents a methodology that supports the design of adaptable buildings through a separation of building components whose replacement rates differ. The methodology contains a number of processes which allow the identification of the relative replacement rates of building components, and the separation of components with different rates. It makes use of graphs to represent the design of buildings, and of graph-theoretic tools to facilitate a systematic analysis of complex buildings that contain a large number of components. The separation of components is achieved through the provision of buffers in the design, and through the design of modules with standard and flexible interfaces.

Modules are defined by their functionality, in addition to their physical dimensions, through an analysis of the user requirements satisfied by their components. Likely future changes in these requirements can be translated into a different modularization of the building. For example, in the illustrative case described in this paper, a partition wall was defined as either one module, or as a number of connected modules, depending on the expected changes. Future research will focus on the question how preassembled modules can be used to facilitate both their efficient installation in a new building, as well as an efficient adaptation of existing buildings. This is likely to be relevant in particular regarding preassembled modules containing mechanical, electrical, and plumbing components.

REFERENCES


Prediction of project cash flow using time-depended evolutionary LS-SVM inference model

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Purpose The ability to predict cash demand is crucial for the operation of construction companies. Reliable cash flow prediction during the execution phase can help managers to avoid cash shortages and to control project cash flow effectively.

Method This paper presents a new inference model, CF-ELSIMT, for cash flow forecasting. The developed CF-ELSIMT utilizes weighted Least Squares Support Vector Machine (wLSSVM) as a supervised learning technique to generalize the mapping function between input and output of cash flow time series. A novel dynamic time function (TF) is employed to determine the weighting values associated with data in different time periods. The dynamic TF allows the model to deal with distinct characteristics in cash flow time series. To optimize the model’s tuning parameters, the new inference model incorporates Differential Evolution (DE) as the search engine. In addition, a machine-learning-based interval estimation (MLIE) approach is used to arrive at the prediction interval of forecasted cash demand.

Results & Discussion The CF-ELSIMT provides construction planners with a point estimate coupled with the lower and upper prediction intervals. Experimental results and comparisons have demonstrated that the newly established model has enhanced the forecasting accuracy.

Key words: construction management, weighted LS-SVM, cash flow forecasting, cost control

INTRODUCTION

In construction industry, cash is a critical factor that imposes influence on project profitability1. Poor cash flow control can lead to project failure for contractors due to liquidity shortage for supporting their daily activities2. Hence, reliable prediction of cash flow time series over the course of a construction project is beneficial since it puts the project manager in a better position to identify potential problems and to develop appropriate strategies to mitigate the negative effects of such on overall project success.

Due to the importance of the problem at hand, various models have been proposed to predict the project cash flow. Boussabaine and Kaka employed neural networks in cash flow forecasting and control3. In addition, fuzzy logic based techniques have also been applied to increase the effectiveness of cash flow analysis conducted under uncertain conditions4, 5. Park et al. proposed a forecasting model for construction projects that considered both variable cost weights and time lag6. However, most of previous models were developed to assist manager in the pre-tendering or planning stage of a project, few researches have addressed the dynamic and time-depended nature of the cash flow prediction problem.

Additionally, prediction of cash flow is often stated in the form of a point forecast7, 8. However, in practice, project managers require not only accurate forecasts of cash flow but also the uncertainty associated with the predictions. Interval estimation includes the upper and lower limits between which a predicted variable is expected to lie with a certain level of confidence. The range restricted by those limits is known as prediction interval (PI) (see Fig. 1). Thus, incorporating prediction uncertainty expressed by prediction interval can help improve the reliability and the credibility of the model outputs.9

Fig. 1 Prediction Interval

Recently, a new framework for achieving prediction interval (PI) which is based on machine learning
technique has been established by Thresha and Solomatine\textsuperscript{9}. The proposed machine learning based interval estimation (MLIE) does not require any assumption and prior knowledge of input data or model error distribution. In their research work \cite{9}, the superiority of the MLIE over existing methods is exhibited. Thus, it is beneficial to incorporate this approach into a forecasting model to obtain the interval estimation.

Proposed by Suykens et al.\textsuperscript{10, 11}, WLS-SVM is an advanced machine learning technique which possesses many advanced features. In WLS-SVM's training process, a least squares cost function is proposed to obtain a linear set of equations in the dual space. Consequently, it is required to deal with a set of linear system which can be efficiently solved by iterative methods such as conjugate gradient\textsuperscript{12}. Furthermore, in this approach, a weighting value is assigned to each error variable\textsuperscript{13}. This feature allows each training data point to contribute differently to the establishment of the regression function and facilitate WLS-SVM to better deal with time series problems such as cash flow prediction.

Another issue in the field of AI is the mechanism for setting models' control parameters. In practice, identifying model's parameters often requires time-consuming trial-and-error processes. Thus, hybridizing the machine learning techniques with an evolutionary algorithm (EA) is a prevalent research direction\textsuperscript{14}. The machine learning techniques with an evolutionary setting models' control parameters. In practice, this approach, a weighting value is assigned to each error variable\textsuperscript{13}. This feature allows each training data point to contribute differently to the establishment of the regression function and facilitate WLS-SVM to better deal with time series problems such as cash flow prediction.

Another issue in the field of AI is the mechanism for setting models' control parameters. In practice, identifying model's parameters often requires time-consuming trial-and-error processes. Thus, hybridizing the machine learning techniques with an evolutionary algorithm (EA) is a prevalent research direction\textsuperscript{14}. Among EA techniques, Differential Evolution (DE)\textsuperscript{15} is a population-based stochastic search engine, which is efficient and effective for global optimization in the continuous domain. Superior performance of DE over other algorithms has been verified in many reported research works.\textsuperscript{15, 16}

Therefore, purpose of this study is to hybridize WLS-SVM, MLIE, APLF, and DE to establish a new inference model for predicting time-cost curve of construction projects. Since the cash flow data are time-dependent, the integrated model employs WLS-SVM to infer the mapping between past and future instances of the time-cost curve. Moreover, APLF is used to determine the weighting values associated with each data. In order to automatically identify the tuning parameters, the new inference model utilizes DE. Additionally, MLIE approach is deployed to calculate prediction intervals of forecasted outputs.

The second section of this paper reviews related literature on WLS-SVM, MLIE, and DE. In the third section, detail of the proposed adaptive time function is introduced. The framework of the proposed model CF-ELSIM\textsubscript{R} is depicted in the forth section. The fifth section demonstrates the experimental results. Conclusion on our study is mentioned in the final section.

**LITERATURE REVIEW**

Weighted Least Squares Support Vector Machine (WLS-SVM)

This section reviews the formulation of WLS-SVM, proposed by Suykens et al.\textsuperscript{13}. Consider the following model, which describes the mapping relationship between a response variable and independent variables:

\[ y(x) = w^T \phi(x) + b \]  

where \( x \in \mathbb{R}^n \), \( y \in \mathbb{R} \), and \( \phi(x) : \mathbb{R}^n \rightarrow \mathbb{R}^m \) is the mapping to the high dimensional feature space. The formulation of WLS-SVM, given a training dataset \( \{x_k, y_k\}_{k=1}^N \), can be given as follows:\textsuperscript{13, 17}

Minimize \( J_\theta(w, e) = \frac{1}{2} w^T w + \gamma \frac{1}{2} \sum_{k=1}^N s_k e_k^2 \) \hspace{1cm} (2)

Subjected to \( y_k = w^T \phi(x_k) + b + e_k \), \( k = 1, \ldots, N \)

where \( e_k \in \mathbb{R} \) are error variables; \( \gamma > 0 \) denotes a regularization constant; \( s_k \in [0,1] \) is a weighting value associated with an error variable.

The above optimization problem stated in (2) can be solved by constructing the Lagrangian and deriving the following dual problem.\textsuperscript{10}

The Lagrangian is given by:

\[ L(w, b, c; \alpha) = J_\theta(w, e) - \sum_{k=1}^N \alpha_k \{ w^T \phi(x_k) + b + e_k - y_k \} \] \hspace{1cm} (3)

where \( \alpha_k \) are Lagrange multipliers. The conditions for optimality are given by:

\[ \frac{\partial L}{\partial w} = 0 \rightarrow w = \sum_{k=1}^N \alpha_k \phi(x_k) \]

\[ \frac{\partial L}{\partial b} = 0 \rightarrow \sum_{k=1}^N \alpha_k = 0 \]

\[ \frac{\partial L}{\partial e_k} = 0 \rightarrow \alpha_k = \gamma s_k, \quad k = 1, \ldots, N \]

\[ \frac{\partial L}{\partial \alpha_k} = 0 \rightarrow w^T \phi(x_k) + b + e_k - y_k = 0, \quad k = 1, \ldots, N \]

After elimination of \( e \) and \( w \), the following linear system is obtained:

\[ \begin{bmatrix} 0 & -Y^T \end{bmatrix} \begin{bmatrix} b \end{bmatrix} = \begin{bmatrix} 0 \end{bmatrix} \]

\[ \begin{bmatrix} Y \end{bmatrix} \begin{bmatrix} a \end{bmatrix} = \begin{bmatrix} 1 \end{bmatrix} \] \hspace{1cm} (5)

where
\[ Y = (y_1, y_2, \ldots, y_n)^T \]  
\[ \alpha = (\alpha_1, \ldots, \alpha_N) \]  
\[ \omega_y = y_1, y_2, \phi(x_1)^T \phi(x_n) + (s_y)^{-1} I \]  
\[ 1 = (1, 1, \ldots, 1)^T \]

And the kernel function is applied as follow:

\[ K(x_i, x_j) = \phi(x_i)^T \phi(x_j) \]

The resulting LS-SVM model for function estimation is expressed as:

\[ y(x) = \sum_{k=1}^{N} \alpha_k K(x_k, x_j) + b \]

where \( \alpha \) and \( b \) are the solution to the linear system (5). The kernel function that is often utilized is Radial Basis Function (RBF) kernel. Description of RBF kernel is given as follow:

\[ K(x_i, x_j) = \exp \left[ \frac{-|x_i - x_j|^2}{2\sigma^2} \right] \]

Machine-learning Based Interval Estimation

This section reviews the machine learning based interval estimation (MLIE), which was proposed by Thresha and Solomatine. The MLIE approach is described in Fig. 2. At first, the point estimation process is carried out. A regression model is implemented to infer the mapping function between input data and the corresponding outputs. The input data points are then separated into different clusters that have similar historical residuals, which are obtained from point estimation process, using fuzzy c-means clustering (FCMC) [18]. When applying FCMC, the number of clusters is commonly selected so that it results in a minimum value of Xie-Beni index.  

\[ P(13) \]
\[ P(14) \]

where \( L_j \) and \( U_j \) are lower and upper PIs for data point \( j \). And \( \mu_{i,j} \) is membership grade of data point \( j \) to cluster \( i \).

The third step is to calculate the PI for each training data point using the weighted mean of PIs of each cluster:

\[ P(15) \]
\[ P(16) \]

where \( P(17) \) and \( P(18) \) are lower and upper PIs for data point \( j \).

Prediction limits (PLs) for each data point are computed as follows:

\[ P(17) \]
\[ P(18) \]
where \( PL_L^j \) and \( PL_U^j \) are lower and upper PLs of predicted output \( j \).

In the final step, a machine learning (ML) technique (e.g., LS-SVM) can be deployed to learn the mapping functions between the input data and the computed PLs for training data. PLs for testing data can be inferred using those underlying functions.

**Differential Evolution**

Differential evolution (DE) is an Evolutionary Algorithm (EA) which is designed for real parameter optimization. \(^{15}\) DE algorithm is based on the implementation of a novel crossover-mutation operator, based on the linear combination of three different individuals and one subject-to-replacement parent (or target vector). \(^{20}\) The crossover-mutation operator yields a trial vector (or child vector) which will compete with its parent in the selection operator. The selection process is performed via selection between the parent and the corresponding offspring. \(^{21}\) The algorithm of differential evolution is shown in Fig. 4. In this figure, it is noted that NP represents the size of the population; \( X_{ij} \) is the \( j \)th decision variable of the \( i \)th individual in the population; \( g \) is the current generation; and \( D \) denotes the number of decision variables. \( \text{rand}(0,1) \) is a uniform random number lying between 0 and 1; and \( \text{mb}(i) \) is a randomly chosen index ranging between 1 and NP.

\[
\text{Initialize population of } NP \text{ individuals}
\]

\[
\text{Do}
\]

- For each individual \( j \) in the population
- Generate three random integers \( r_1, r_2, \text{ and } r_3 \in \{1, \ldots, NP\} \) with \( r_1 \neq r_2 \neq r_3 \neq j \)
- Generate random integer \( i, m \in \{1, \ldots, D\} \)
- For each parameter \( X_{ij} \)
  \[
  U_{ij} = \begin{cases} 
  X_{ij} + \alpha k (X_{mij} - X_{r3ij}) & \text{if } \text{rand}(0,1) < CR \text{ or } j = \text{mb}(i) \\
  X_{ij} & \text{otherwise}
  \end{cases}
  \]

- Replace \( X_{ij} \) with the offspring \( U_{ij} \) if \( U_{ij} \) is better
- End For
- Replace \( X_{ij} \) with the offspring \( U_{ij} \) if \( U_{ij} \) is better
- End For

Until the stopping condition is met.

**Fig. 4 Differential Evolution Optimization Algorithm**

In the selection process, the trial vector is compared to the target vector (or the parent). \(^{16}\) If the trial vector can yield a lower objective function value than its parent, then the trial vector replaces the target vector. The selection operator is expressed as follow:

\[
X_{ij+1} = \begin{cases} 
U_{ij} & \text{if } f(U_{ij}) \leq f(X_{ij}) \\
X_{ij} & \text{if } f(U_{ij}) > f(X_{ij})
\end{cases}
\]

(19)

where \( X_{ij} \) represents the parent vector at generation \( g \). \( U_{ij} \) denotes the trial vector at generation \( g \). \( X_{ij+1} \) is the chosen individual which survives to the next generation \( g+1 \).

The optimization process iterates until the stopping criterion is satisfied. The user can set the type of this stopping condition. Commonly, maximum generation \( G_{\text{max}} \) or maximum number of function evaluations \( \text{NFE} \) can be applied as the stopping condition. When the optimization process terminates, the final optimal solution is available for the user assessment.

**Adaptive Piecewise Linear Function for Weighting Time Series Data**

Real-world time series data are often unbalanced due to the fact that recent data can provide more relevant information than distance ones. Therefore, time series data should to be weighted differently. Instead of using fixed time functions, this study proposes an adaptive piecewise linear function (APLF) for weighting data.

The role of the APLF is to determine a weighting value to each data point in the training process. The time function assigns small weighting values for data points at the initial phase of a project. Meanwhile, data points recorded at the later phase are coupled with greater weighting values (see Fig. 5). Using the proposed APLF, the time horizon of a completed project is divided into several domains. Each domain is characterized by a linear time function described as follow:

\[
s_i^k = s_0 + a_k(t_i), \quad k = 1, \forall i \in R_k
\]

(20)

\[
s_i^k = \max_{\forall i \in R_k} (s_i^{k-1} + a_k(t_i)), \quad k \geq 1, \forall i \in R_k
\]

(21)

\[
0 \leq a_k \leq a_k^{\text{max}}
\]

(22)

\[
a_k^{\text{max}} = \frac{(1 - s_0)}{n_k}, \quad k = 1
\]

(23)

\[
a_k^{\text{max}} = \frac{(1 - \max_{\forall i \in R_k} (s_i^{k-1}))}{n_k}, \quad k \geq 1
\]

(24)

where \( s_i^k \) denote the weight value for data point \( i \) in the \( k \)th domain. \( s_0 \), varying between 0 and 1, is the initial value of the time function in the first domain. \( a_k \) represents the slope value of the time function in the \( k \)th domain. \( R_k \) is the set of time periods in the \( k \)th domain. And, \( n_k \) is the index of the last time period in the \( k \)th domain. For instance, if a domain \( j \) contains four time periods: 3, 4, 5, and 6, the corresponding \( n_j \) is 6. The Eq. (20) and (21) calculate the weighting value for each time period. The Eq. (22), (23), and (24) control the magnitude of the slope parameters so that every
The weighting value is of the range \([0, 1]\).

![Fig. 5 APLF for weighting time series data](image)

For the first domain, the time function has two free parameters: the initial value \((s_0)\) and the slope \((a_1)\). The time function for other domain only needs the slope parameter to specify its shape. Consider the case in which each project has \(M\) completion periods, the project duration is separated into \(n\) domains. Hence, there are \(n+1\) tuning parameters that needed to be specified. When the APLF is integrated into the overall model, its tuning parameters are automatically optimized by the search engine.

**Cash Flow Prediction Using Time-dependent Evolutionary LS-SVM Inference Model (CF-ELSIMT)**

This section dedicates in describing the proposed prediction model, named as CF-ELSIMT, in detail. The establishment of the model (see Fig. 6) is accomplished by a fusion of various prevalent AI techniques. CF-ELSIMT employs WLS-SVM as the supervised learning algorithm for mining the implicit patterns in the series. Moreover, the new forecasting model incorporates the MLIE for achieving interval prediction. Finally, DE, an evolutionary optimization algorithm, is utilized to automatically identify the optimal values of tuning parameters.

![Fig. 6 Cash Flow Forecasting Using Time-depended Evolutionary Least Squares Support Vector Machine Inference Model (CF-ELSIMT)](image)

The database used in the paper, collected from a construction contractor in Taipei, was generated in the process of executing high rise projects between 1996 and 2006. This database contains percentage of expenditure cash flow taken from 13 completed construction projects reported in. Table 1 illustrates the cash flow data for one project in the database. The CF-ELSIMT utilizes 8 projects as training set, 2 projects as validating set, and 3 projects as testing set. Standard cumulative cost-time curves were employed to model cash flow prediction.

**Table 1. Example of expenditure cash flow for one construction project**

<table>
<thead>
<tr>
<th>Case</th>
<th>Input pattern</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st period</td>
<td>2nd period</td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>2.7</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>5.1</td>
<td>9.7</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>16</td>
<td>75.5</td>
<td>83.5</td>
</tr>
<tr>
<td>17</td>
<td>83.5</td>
<td>87.6</td>
</tr>
</tbody>
</table>
(2) Tuning parameter initialization: The construction of the prediction model is dependent on a set of tuning parameters (see Table 2). The parameters of APLF consist of the initial value \( s_0 \) and the slope value \( a_i \), which are needed for weighting data. The regularization parameter \( \gamma \) and the kernel function parameter \( \sigma \) are required for the WLS-SVM. The number of clusters \( C \) is needed to be specified for the fuzzy c-means clustering process.

Table 2. Ranges of model's tuning parameters

<table>
<thead>
<tr>
<th>Tuning parameter</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial value of APLF ( s_0 )</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Slope value of APLF ( a_i )</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Regularization parameter ( \gamma )</td>
<td>0.001</td>
<td>10000</td>
</tr>
<tr>
<td>Kernel function parameter ( \sigma )</td>
<td>0.001</td>
<td>1000</td>
</tr>
<tr>
<td>Number of cluster ( C )</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

(3) Adaptive piecewise linear function (APLF) for weighting data: Each training data point is weighted according to the APLF. It is noted that the weights computed from the APLF ranges from a relatively small starting value \( s_0 \) to 1. Hence, the most recent data point is treated as the most important and thus, received the highest value of 1. Meanwhile, the most distant data point is considered as the least important and given the smallest value of \( s_0 \).

(4) WLS-SVM for point estimation: In this step, LS-SVM is deployed to learn the mapping function between the input (X) and the output (Y) derived at the previous step. The training process requires the two parameters \( \gamma \) and \( \sigma \) that are acquired from the DE searching. These parameters play an important role in determining the model’s prediction accuracy.

(5) DE searching: At each generation, the optimizer carries out the mutation, crossover, and selection processes to guide the population to the optimal solution.

(6) Interval estimation: This step employs the MLIE approach established by Thresha and Solomatine [9]. In the fuzzy clustering process, the search engine is employed to find the number of cluster \( C \). After the prediction limits for each training data point are computed, two LS-SVM models are employed to learn the regression function between input data and the two PLS. The tuning parameters of LS-SVM for interval estimation are identical to that of LS-SVM for point estimation, which are automatically identified by the search engine.

(7) Fitness evaluation: In ELSIM, in order to determine the optimal set of tuning parameters, the following objective function is used in the step of fitness function evaluation:

\[
F_{\text{fitness}} = \alpha \times E_{\text{tr}} + \beta \times E_{\text{va}} + \theta \times S
\]

In Eq. (16), \( \alpha, \beta, \) and \( \theta \) are weighting coefficients. \( E_{\text{tr}} \) and \( E_{\text{va}} \) denotes the training error and validating error, respectively. The training and validating errors herein are Root Mean Squared Error (RMSE). \( S \) represents the Xie-Beni index [19], which is calculated as followed:

\[
S = \sum_{i=1}^{C} \mu_i^2 \sum_{j=1}^{n} \left\| V_i - X_j \right\|^2
\]

where \( X_j \) denotes the data point \( j \). \( V_i \) is the center of cluster \( i \). And, \( n \) is the number of data points. (8) Stopping condition: The DE's optimization process terminates when the maximum number of generation is achieved. (9) Optimal prediction model: When the program terminates, the optimal set of tuning parameters has been successfully identified. The CF-ELSIM-T is ready to carry out forecasting tasks.

EXPERIMENTAL RESULT

This section validates the performance of the proposed prediction model. To illustrate that CF-ELSIM-T is capable of delivering accurate and reliable results, the outcome of the proposed model is benchmarked with Evolutionary Support Vector Machine Inference Model (ESIM). In order to evaluate the accuracy of EAC point estimation, RMSE is employed (see Table 3). RMSE of CF-ELSIM-T for training is 0.013. Moreover, it is noticed that CF-ELSIM-T utilized the APLF for weighting data; the optimal shape of the weighting function is shown in Fig. 7. Meanwhile, RMSE for testing projects 1, 2, and 3 are 0.020, 0.041 and 0.024, respectively. It is observable that the new model outperformed the benchmark approach in prediction accuracy since the prediction error of ESIM for two testing projects are 0.036, 0.048, and 0.052.
Furthermore, to assess performance of the constructed prediction interval, Prediction Interval Coverage Probability (PICP) and Mean Width of Prediction Interval (MPI) are utilized (see Table 4). When the level of confidence (LOC) is 90%, the PICP and the MPI of the proposed model for the two testing projects are 90% and 0.09, respectively. Those two values are calculated to be 96% and 0.13 in the case of 95% LOC. Fig. 8 illustrates the result of interval prediction of CF-ELSIMT for one testing project with 95% LOC. Observably, the proposed model is accurate in interval forecast of project cash flow. It has achieved acceptable values of PICP value corresponding to relatively small values of MPI.

**CONCLUSION**

This paper has presented a new prediction model, named as CF-ELSIMT, to assist construction managers in dealing with forecasting of project cash flow. The proposed model was developed by a fusion of various advanced AI techniques, namely: WLS-SVM, APLF, MLIE, and DE. The WLS-SVM is utilized to infer the input/output mapping function of cash flow data. The APLF helps the model to be more appropriate in coping with real-world time-dependent data. Meanwhile, to address the uncertainty of prediction results, the model integrates the MLIE approach. Using MLIE, the prediction interval is constructed by evaluating the uncertainty inherent in the data set, without any assumption or prior knowledge of model’s error. Moreover, DE searching algorithm is utilized to identify the most appropriate set of tuning parameters without the need of experience or trial-and-error process in parameter setting.

Consequently, the model’s output consists of the point estimation coupled with the lower and upper prediction intervals, given a certain level of confidence, to emphasize the forecasting uncertainty. Furthermore, the newly developed model has the ability to operate automatically without human intervention and domain knowledge. Simulation result and performance comparison have proved the strong potential of CF-ELSIMT as an alternative for cash flow forecasting. Currently, CF-ELSIMT has a limitation is that the model is built using the database collected from one construction contractor in Taipei. Although the data are quiet homogeneous and capable of facilitating cash flow estimation effectively, more historical cases from different contractors should be incorporated to enhance the generalization of the prediction model. On the other hand, all of recorded projects are high-rise buildings; hence, construction projects of other types, such as highway or steel structures can be worth investigated. It is because other project types may possess different characteristics. Nevertheless, the processes of collecting new data cases are of great effort and time-consuming. Hence, we would like to consider these to be promising future research directions.

**References**


A survey of ergonomic parameters of shoppers

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Purpose Shoppers are used every day to save energy and ease carrying. The lack of attention to ergonomic considerations and safety parameters can lead to injuries and related inconveniences. The purpose of this study is to assess ergonomic factors in different types of trolleys and compared to other shoppers. This will help identify proper solutions in designing an ergonomic shopper.

Method In this case study, most information was obtained by interview, in-depth observation and through a questionnaire. A total of 30 people with an average age of 45 volunteered to take part in the study. The findings were obtained in public places in two cities in Iran: Tehran and Mashhad.

Results & Discussion Initial results revealed that when shopping, the Iranian users’ requirements were not adequately addressed. This was due to the lack of proper design and manufacturing by Iranian companies. Poor design provoked reactions and particular behaviour in users. Our results indicate dissatisfaction in the use of shopper, preventing users from buying one. Certainly, modification in shopper design with emphasis on ergonomic parameters can improve physical conditions and reduce related injuries. This study provides recommendations on how this can best be done.

Keywords: shoppers, pushing and pulling forces, handling, design factors

INTRODUCTION

Shoppers are assistance tools to save energy and ease carrying. The lack of attention to ergonomic considerations and safety parameters can lead to injuries and related inconveniences among Iranian adults and aging. This study provides recommendations in shopper design with emphasis on ergonomic parameters which improves physical conditions and reduces related injuries, hence some questions such as what forces cause to reduce injuries in arm, shoulder and low back muscles, and also what factors decreasing required forces for carrying of shopper, were answered with considering ergonomic problems in available samples.

LITERATURE REVIEW

Enid W.Y. Kwong et.al recommended that Lightness and easy storage, a pulling and pushing motion, suitability for use on stairs, and adjustable handle height were the trolley features most frequently expected by the customers. Women were more likely to be current users because they have more opportunities to shop and to purchase goods and, also, elderly people are unable to carry heavy loads, and so tend to be users of shopping trolleys [1].Therefore, other researchers recommended design factors for different types of trolleys that adds some data for ergonomic parameters of shopping trolley.

- Measure of Wheels: Drury’s team showed that wheels with a 25 cm diameter were 16% faster than those with a 7.5 cm diameter. And the government of the Canadian province of Alberta suggested that carts with larger wheels are more stable, particularly when used over rough surfaces and in narrow gaps.
- Type of wheels: Front wheel swiveling required about10% less pushing and pulling forces.
- Handle height: The Alberta government recommended that the handle should be at a height between the elbow and hip for pushing and between the hip and knee for pulling for optimal push and pull force capabilities.
- Handle diameter: D. Welcome et al suggested hand–handle contact force is strongly dependent upon not only the grip and push forces but also the handle diameter.
- Handle angle: Okunribido and Haslegrave (1991) found that people generate higher push forces at higher handle heights, while higher pull forces are generated at lower handle heights.

316
rying. Wissenden and Evans (2000) verified a 44% decrease in steering errors with an angled handle on supermarket trolleys that allowed the arms and hands to be neutral.

- **Center of mass:** Idsart Kingma et al suggested that the design of Dutch two-wheeled containers can be improved by moving the COM of the loaded container in the direction of the axis of the wheels and by slightly raising the height of the handles [6]. Kingma et al verified the center of load mass should be low for four-wheeled carts and should be close to the wheel axles for one- and two-wheeled hand trucks.

- **Force direction:** M.P. De looze et al observed, the force direction was affected by the horizontal force level and handle height so that these were reflected in changes on the loads on the shoulder and low back in pushing and pulling wheeled carts.

- **Pushing and pulling forces:** A pulling motion may also cause the cart also to run over users’ feet, strike their ankles, and force them to stretch their arms behind their bodies, all of which increase the risk of pain and injury. Marco J.M et al. showed that the magnitude and direction of the exerted push force and the trunk inclination affect low back load. K.S. Lee et al found pushing a cart results in lesser lower-back loading than pulling and also found body weight affected the lower-back loadings more significantly in pulling (50% increase as body weight increased from 50 kg to 80 kg) than in pushing (25% increase). B. Schiby et al indicated that the torques at the low back and the shoulders are lower during pushing and pulling of two-wheeled waste containers compared with lifting of bags. Na Jin Seo showed the handle parallel to the exertion direction decreased 10% pull/push forces compared to the handle perpendicular to the exertion direction and also observed the low friction aluminum handle decreased 17% Pull/push force compared to the high friction rubber handle. Martin and Chaffin found that vertical hand heights of between 50 and 90 cm allowed maximum pushing capability. Khaled W. Al-Eisawi et al recommended that hand forces in pushing and pulling carts are affected by cart load and handle height and also found for heavier cart loads, lower forces are applied at higher handle heights.

Marco J. M. Hoozemans suggested that in pushing the (hand) force is directed away from the body and in pulling the force is directed toward the body.

### MATERIALS AND METHODS

**In this case study, the main data gathering methods were included by interview, in depth observation and questionnaire.** A total of 30 people with an average age of 45 volunteered to take part in the study. The findings were obtained in public places in Tehran and Mashhad. And also the gender difference has no observably effect on analysis of information. The questionnaire is emphasized on various parameters such as way conditions for caring of shopper, keeping stable and balance in difference surfaces, the rate of energy consumption, easy of carrying, over stretching arms, the height and texture of handle, body structure.

**Data analysis**

With respecting of observed samples, there were no high qualities in Iranian and Chinese goods. Initial results revealed that when shopping, the Iranian users’ requirements were not adequately addressed. This was due to the lack of proper design and manufacturing by Iranian companies, so that this problem provoked reactions and particular behaviour in users. The pictures depict some of above problems:
Fig. 1. Sampled cases of shopper
With respecting reviews and analysis of questionnaire, it can be concluded that about 50% of people unsatisfied of carrying of shopper in different surfaces. 20% supposed that it helps in energy saving. 73.4% were injured in arm's stretching because of unadjustable handle height and unsuitable body and wheels. 66.7% complained about the unbalance of shopper. 70% supposed that is not suitable for carrying of deference spaces. Finally, 80% had some problems in coming up and down from stairs and so that had to lift it.

RESULT AND DISCUSSION:
Some problems in design of shopper can be viewed in the following:

- **Wheels:** transferring body vibrations by hard wheels, not easy in maneuver by non swivel wheels and getting stuck in the gap and unsuitability on stairs by small wheels.
- **Handle:** unsuitable angle, height and texture of handle
- **Body structure:** inadequate capacity and pressure exertion to items, unbalance body, unsecure loading due to unsuitable door, not easy to clean and low durable and quality.
- **Pull and push forces:** paying no attention to push force of trolley.

It doesn't meet satisfaction because manufactures didn’t pay enough attention to important factors like safety and security in designing of shopper; and consequently, the rate of buying this product has significantly reduced.

**Recommendations:**
This study is the first to investigate problems and customer views on shoppers in Iran. The findings lead to modification methods with emphasis on ergonomic parameters for design of an ergonomic shopper that is acceptable to adults and aging in Tehran, Mashhad and other similar cities.

**Design factors:**
1. **Combination of pull and push forces:** The pushing force of trolley is less dangerous and safer than pulling one for body, therefore, moving forward and pushing it in straight line results in least physical stress.
2. **Wheels:** Rubber or polyurethane tire and spring mechanism (Anti shock system) should be used for rough places and reducing vibration in shopper, respectively. In addition to, the shopper can be capable of turning through 360 degrees by front swivel wheel.
3. **Measures of Wheels:** Large wheels for climbing up and down stairs and front swivel wheels should be used for lower 10% pushing and pulling forces and high maneuverability.
4. **Brakes:** Brake lever is used to keep fixes it in incline surfaces.
5. **Body structure:** Strong and stable body for keeping load balance prevents to injuries in wrist.
6. **Weight:** Light materials like Aluminum in its structure results in reducing physical stress.
7. **Handle angle:** Handle of angled at 30-35 degrees from vertical is used for easy to exerted push force.
8. **Handle height:** Adjustable handle (60-95 cm from the floor) is used for adjusting the height of trolley handle to body.
9. **Hand-handle texture:** Handle with soft foam increases more gripping and reduces pressure on hand.
10. **Foldable structure:** The shopper can become flat for easy storage and easy to carry.
11. **Type of buying:** Special places are devoted for fragile and sensitive goods to prevent using several bags to gather (adjustment with type and amount of buying).
12. **More facilities:** Some more items are added for aging people like first aid kit, place for sitting, magnifying glass for easy reading of descriptive label (product information), safety lights for walking at night and pockets for keeping an umbrella, a walking stick, notebook, mobile, money, keys and est.

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**REFERENCES**

Sonification system for aging Taiwanese people

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Purpose Aging has become a significant problem in the recent years, due to the aging baby boomers. Most of the supervision systems use vision to perform care functions. However people usually cannot watch video all the time, therefore the proposed sonification for aging Taiwanese is used to express a particular situation at the children or nursing home, including both acoustic instrumental sound for the event-triggered actions, and algorithmic composition to represent various environment situations. The nursing system can easily retrieve their seniors’ situation anytime according to the transmitted audio signal and music via a network. Method The proposed Chinese music sonification system (CMSS) for older people can be implemented into two sections. Section 1: Event-triggered sound is designed using Chinese instrumental audio samples performed by pipa, erhu, etc. Event-triggered sound is based on the input of various actions of aging people, such as watering, exercising, toileting, dining, sleeping, etc. Section 2: Computer-composed music, is designed using automated stochastic process of MIDI-data with various moods and situations mapped into music features, including musical scale, harmony, tonality, and rhythm. There are five Chinese music modes used for the musical scale. Among them Gong, Jiao, and Jiao are closer to the major mode in western music, while Shang and Yu are similar to the minor mode, therefore positive emotions will be mapped into a major-mode music, and the negative emotions will be correlated to a minor-mode music. Results & Discussion CMSS is based on the hybrid event-triggered sound and computer composed music. Event-triggered sound is the pre-recorded discrete audio samples, while computer composed music is the calculated continuous MIDI-rendered audio in real-time. A questionnaire is designed for the seniors to listen to the result of the CMSS, and most of them are satisfied with this innovated design. Action data is used for computer composed music calculation via CCD, RF ID, or any other wireless technology, and environment data is determined by sensors such as bio-feedback, temperature, etc., providing data for event-triggered sound. CMSS are implemented with computer music software Max/MSP, to perform CMSS for the seniors living in Taiwan.

Keywords: Chinese music sonification system, aging boom, algorithmic composition

INTRODUCTION

Aging problem is becoming significant in the recent years, about the baby boomers1. Most of the supervision systems use vision to perform elders’ care function. However people usually cannot watch video all the time, therefore the proposed sonification2,3 for the aging Taiwanese is used to express situation for their children or nursing home in Taiwan, including both acoustic instrumental sound for the event-triggered actions, and algorithmic composition4-7 to represent various environment situations. The nursing system can easily retrieve their elders’ situation anytime according to the transmitted audio signal and music via network. Method is based on the proposed Chinese Music Sonification System (CMSS) for aging people including event-triggered sound recorded by Chinese instrumental audio samples, and computer composed music using automated stochastic process of MIDI data with various moods and situations mapped into music features. There are five Chinese music modes (Gong, Shang, Jiao, Zheng, and Yu)8 used for the musical scale. Among them Gong, Jiao, and Jiao are closer to major mode in western music, while Shang and Yu are similar to minor mode, therefore the positive emotion will be mapped into a major-mode music, and the minor emotion will be correlated to a minor-mode music. The proposed computer composed music using automated background music composition technique, which integrates the new trends of algorithmic composition, music theory, human-computer-interface (HCI), emotion, tension, etc. Hopefully the conventional background music composition can be not only played as a constant loop, but also performed via the scene settings of the content related to aging people. The research is based on algorithmic composition to generate the various music parameter distributions, therefore the generated music can be composed automatically according to the variation of the scenarios. The discussion of various scenarios mapped into a 2-D emotion coordinate9,10,11 to generated affective-related music is presented too.

CMSS is based on the hybrid event-triggered sound and computer composed music. Event-triggered sound is the pre-recorded discrete audio samples, while computer composed music is the calculated continuous MIDI-rendered audio in real-time. Action
data is used for computer composed music calculation via user’s selection currently, or in the future via CCD, Microsoft Kinect12, or any other wearless technologies, and environment data is determined by sensors such as bio-feedback, temperature, etc., providing data for event-triggered sound. CMSS is implemented with computer music software, to perform CMSS for the elders living in Taiwan.

**METHOD**

Since melody and styled accompaniment can be generated by the proposed automated composition for the computer composed music, a 2-D emotion map, as shown in Fig. 1, is used to compose music automatically with the emotion-music feature mapping and the proposed emotion trajectory which can be related to the situations of aging people.

![Fig.1. 2-D Emotion Map for CMSS System](image)

The feature selection is also important in music style classification and there is a catalogue of features that can be used to classify was defined13. In the catalogue of features, we used two categories, timbre and texture, in our rules. Timbre and texture will be the essential factor of our arranged accompaniment. Furthermore, rhythm is always discussed when it talks to music style. Three types of features will be introduced in this paper. Firstly, pitch range is the only one feature based on pitch that we choose to use in our accompaniment generation. It means the difference in semitones between the highest and the lowest note. In general, most features based on pitch in classification are defined to be used in the melody. However, we concern about the features of accompaniment in this part. So we use pitch range only to place restrictions on pitch of our accompaniment. Secondly, many types of music are recognized by their own rhythm pattern. When people hear the particular rhythm pattern, they will recall that kind of music on the moment. We use rhythm complexity which is defined as the measures closest to human performance difficulty in rhythm14. Thirdly, timbre or instrument selection plays an important role in accompaniment. Instrument timbre will be affect ac-

compainment arrangement profoundly. All features based on timbre are described as followed: (1) Orchestration: A features array with one entry for each of the 128 GM instruments presents which of the 128 MIDI instruments are played. (2) Number of Pitched Instruments: Total number of General MIDI instruments that were used to play at least one note. (3) Number of Un-pitched Instruments: Total number of MIDI Percussion Key Map instruments that were used to play at least one note. In music, texture determines the overall quality of a piece. Two features based on texture are described as followed: (1) Maximum Number of Independent Voices: Maximum number of different channels in which notes have sounded simultaneously. (2) Simultaneity: Maximum number of notes sounding simultaneously.

Method As shown in Fig. 2, the proposed CMSS for elder people can be implemented into two parts. Part 1: Event-triggered sound, is designed using Chinese instrumental audio samples performed by pipa, erhu, etc. Event-triggered sound is based on the input of various actions of aging people, such as watering, exercising, toileting, dining, sleeping, etc. Part 2: Computer composed music, is designed using automated stochastic process of MIDI data with various moods and situations mapped into music features, including musical scale, harmony, tonality, and rhythm.

![Fig.2. CMSS System for the elder Taiwanese People](image)

**Implementation**

The implementation of event-triggered sound is basically a set of pre-recorded sound performed and pre-recorded by Chinese instruments, while computer composed music is designed by computer program. The automated composition techniques is applied for the computer generated music using a 2-D emotion coordinate system to map the valence and arousal data from the state of the emotion trajectory into music features, including rhythmic roughness, temp, articulation, mode brightness, harmony complexity, and pitch register, as shown in Table 1.
Table 1. The Mapping Relation between Music Features and Emotion Valence / Arousal

<table>
<thead>
<tr>
<th>Valence</th>
<th>Low ↔ Valence ↔ High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Music features</td>
<td>Smooth ↔ rhythmic roughness ↔ rough</td>
</tr>
<tr>
<td></td>
<td>Slow ↔ tempo ↔ fast</td>
</tr>
<tr>
<td></td>
<td>Legato ↔ articulation ↔ staccato</td>
</tr>
<tr>
<td>Arousal</td>
<td>Low ↔ Arousal ↔ High</td>
</tr>
<tr>
<td>Music features</td>
<td>Low ↔ mode brightness ↔ High</td>
</tr>
<tr>
<td></td>
<td>Low ↔ harmony complexity ↔ High</td>
</tr>
<tr>
<td></td>
<td>low ↔ pitch register ↔ high</td>
</tr>
</tbody>
</table>

In this paper Chinese mode is used for music generation, and “mode” refers to the variance between major and minor which is well defined in the literatures of the western music theory. Modulation in parallel keys between major and minor can be used to make the generated music performed from positive to negative emotion, where Chinese Gong mode is selected as the “major key”, and Chinese Yu mode is used as the “minor key”\(^{[11]}\). An example of the parallel keys is specified in Fig. 4 which specifies two scales in the scores to implement for our proposed CMSS.

![Note Name C D E G A](image1.png)
![Fig.3. C-Gong Mode Scale Definition](image2.png)

![Note Name C E♭ F G B♭](image3.png)
![Fig.4. C-Yu Mode Scale Definition](image4.png)

The only difference between the major scale and the harmonic scale is the 3\(^{rd}\) note and the 6\(^{th}\) note, which can be manipulated with the probability control to guide the “trending” for major and minor keys. With using this point, when the data value of X coordinate is big enough, then the major key can be generated. When the X value is decreased, then the appearance rate of E-nature, 3\(^{rd}\) note of the major key, and A-nature, 6\(^{th}\) note of the major key, is lowered, and the E-flat, 3\(^{rd}\) note of the minor key, and B-flat, 7\(^{th}\) note of the minor key, begins to show up after the X value is across the X axis to the negative.

In addition to music scale, more music features can be used to perform the probability control for automated composition, including chord progression, rhythm, etc. In Fig. 5 Markov Chain is used to control the first-order states transition (S1, S2,..., Sn), and the correspondent probabilities P1, P2, ..., Pn can be assigned according to the emotion-music features mapping relation, as shown in Fig. 5.

![Fig.5. Markov System for the CMSS Automated Music Composition](image5.png)

Finally the emotion-driven music data can be mapped into the CMSS environmental situated data according to the scenario of the aging people, including weather, temperature, season, and time, as shown in Table 2, and then the CMSS automated music composition can be implemented.

Table 2. CMSS Environment – Emotion Mapping

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Happy</th>
<th>Angry</th>
<th>Sad</th>
<th>Dreamy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>Sunny</td>
<td>Heavy Rain</td>
<td>Small Rain / Cloudy</td>
<td>Normal</td>
</tr>
<tr>
<td>Temperature</td>
<td>Hot</td>
<td>Hot</td>
<td>Cold</td>
<td>Warm</td>
</tr>
<tr>
<td>Season</td>
<td>Summer</td>
<td>Summer</td>
<td>Autumn / Winter</td>
<td>Spring</td>
</tr>
<tr>
<td>Time</td>
<td>Morning</td>
<td>Noon</td>
<td>Dusk</td>
<td>Night</td>
</tr>
</tbody>
</table>

Result

The result of the CMSS is currently simulated and obtained by the mapping from action and environment select from aging people, and the scenario-emotion data mapping. Currently most of the aging people subjects satisfy the result of CMSS. In the future more sensor-based data including CCD or Microsoft Kinect can be used to implement the context-aware system for CMSS.
CONCLUSION
The proposed CMSS shows the potential to perform the sonification function of aging people situation for either care centers of children without the need of supervision by eyes. In the future the sensor-based technology will be integrated with CMSS based on our simulation result, to perform more efficient and accurate function for our aging people.

ACKNOWLEDGMENT
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References
Application of queuing theory in construction industry

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Purpose Each production process in construction is closely connected with the question of costs and deadlines. In every project an investor or customer, as well as the construction company, has to meet the planned completion date and the estimated costs associated with the construction. In practice, determining the duration of construction at minimum costs is still not based on the reliable calculation, and in the planning of costs, the connection between terms and financial costs is rarely taken into account. Method The queues theory examines systems with operating channels, where the process of queues formation takes place and subsequent servicing of the customers by servicing centers. The main objective of the queues theory is to determine the laws under which the system works, and further to create the most accurate mathematical model that takes into account various stochastic influences on the process. The entire construction process can be examined from the point of view of a customer who is waiting in the queue and is interested primarily in the waiting time, as well as from the point of view of servicing centers. A waiting element decides if you join the queue, or to go to another system entirely. In terms of servicing centers, the priority is to determine the occupancy of the channel and the probability of failure, including the time of repair. A servicing center should also reliably identify the time per customer service, taking into account the current construction task. Results & Discussion The present study demonstrates that it is possible to simulate the complex process of construction, containing hundreds of individual construction processes, mathematically and technically, with a number of simplifications, and then perform various calculations and changes for effective and long-term planning of construction. The mathematical simulation should show that some variants of machines combinations fail to accomplish the task under the given conditions, some will not be optimal in terms of costs or other parameters, other variants will be optimal in the view of costs required to fulfill the construction task. The simulation software allows a look at the results in graphical form or to export data to other programs. Application of the queues theory allows the introduction into the system waiting time the servicing elements and to approximate the mathematical model to a real working tasks on site.

Keywords: queues theory, optimal choice, machines combination, construction, simulation

INTRODUCTION Each production process in construction is closely connected with the question of costs and deadlines. An investor or customer, as well as construction companies themselves in every project have to meet the planned completion date and the estimated costs associated with the construction. In practice, determining the duration of construction at minimum cost is still not founded on a reliable calculation, and in the planning of costs, the connection between terms and financial costs is rarely taken into account. At present, some programs are available for the analysis of building production and for scheduling with the help of network graphs, timetables and their optimization. A further supporting facility to optimize the prices is so called internal corporate guidelines; construction companies produce them depending on their own experience and statistical values. Some of these documents are then used to optimize the use of machinery and to create building plans. Other similar information instruments, especially for the optimization of construction processes, do not yet exist, or they are produced only in a small and evidently insufficient volume. In particular, the sphere of the optimal choice of machinery is still in its early stages of development, and a software, which would allow an easy optimal choice of machinery in terms of minimizing labour content and costs, fuel consumption, time of construction, environmental impact, etc., including relevant data, does not exist on the internet basis.

THE QUEUING THEORY The current practice does not allow construction companies to perform detailed time-consuming calculations of optimization during formulation of their offers. An offer is usually focused on the contract price, which has to match the situation in the construction market. Optimization steps are therefore made only after the contract is signed. This study is devoted to the creation of a technical and mathematical model and to searching the methods leading to the optimization of construction processes (minimization of labor and costs, fuel consumption, time of construction, environmental impact, etc.) by means of special simulation software. The queuing theory examines systems with operating channels, where the process of queues formation
takes place and subsequently the servicing of the customers by servicing centers. The main objective of the queuing theory is to determine the regularities under which the system works, and further to create the most accurate mathematical model that takes into account various stochastic influences on the process. The entire construction process can be examined from the point of view of a customer who is waiting in the queue and is interested primarily in the waiting time, as well as from the point of view of servicing centers. A waiting element decides in what queue to be included or whether to go to another system entirely. In terms of servicing centers, the priority is to determine the occupancy of the channel and the probability of failure, including the time of repair. A servicing center should also reliably identify the time of customer servicing, taking into account the current construction task.

As a result of the application of the queuing theory, a mathematical model should provide the data regarding the optimal design of servicing centers and, at the same time, determine the number of customers taking into account the optimization parameters. The parameters, under which the construction process will be optimized, may be the following: time, number of failures, fuel consumption, financial costs, environmental impact etc.

The queuing theory appeared in the early 20th century. Fundamentals of the theory were developed by Danish mathematician Agner Krarup Erlang (1878-1929), who examined the development of call centers. According to D.G. Kendall, any system of the queuing theory can be classified according to the following combination of letters and numbers:

![Fig.1. Classification of the queuing theory](image)

where A – describes the input stream of elements, B – describes the probability distribution during service time, C – describes the number of service lines, D – specifies the maximum number of elements in the system, E – describes the queue discipline (finite, infinite, FIFO, LIFO, etc.).

The parameters "A" and "B": in place "A" and "B" may be presented by the following symbols:

- M – for exponential distribution,
- D – for constants (deterministic intervals),
- KK – for Erlang distribution of k-type,
- G – any distribution.

Basic structure of the queuing system is illustrated in Figure 2.

For the optimization of a construction process, a closed system is more convenient, where customers given a certain time after the service return back into the system and go to the queue again. Under a closed process there is understood a situation, where the source of requirements is final. The queue length is limited and the processing of customers’ requirements is done according to the FIFO method (first in - first out).

As an example of the application in use there can be given an optimization of construction machinery at the stage of "earth works", where the role of servicing centers is performed by the loaders or excavators (number C) and the role of customers is played in the system by trucks or dumpers (number D). We investigate a system where D is greater than C.

For each construction process, a time unit can be determined according to the depth of view on the mathematical model of optimization, for example, minute, hour, shift, week, month etc. For a proper functioning of the mathematical model of the queuing theory application, the following range of conditions has to be met:

- input of an element into the queue can occur at any moment of time;
- the number of inputs during the time interval depends on the length of the interval and the type of distribution of a servicing centre performance (e.g. uniform, power-series, falling or rising) and the scheme of a servicing machine performance is given by the parameters of the construction task; these are determined before the mathematical simulation and do not change during the mathematical modelling;
- the probability, that in the interval of the length δT occurs, more than one input converges to zero more quickly than the length of the interval δT;
• the average number of inputs per the unit of
time is equal to \( \lambda \).

To calculate the characteristics of the system, the following formulae have to be used. The service intensity can be determined as follows:

\[
\rho = \frac{\lambda}{C \cdot \mu},
\]

where: \( \lambda \) is a parameter of the exponential distribution, which characterizes the time spent by an element outside the operating system, for example, removal of soil to landfill and return of the truck back to the servicing centre; \( \mu \) is a parameter of the exponential distribution, which characterizes the time spent by an element during service, for example, soil loading on a truck by a loader.

The probability of \( P_k \) function, that in the time interval of the length \( T \) number of elements \( k=1, ..., C \) enter the system, can be expressed as follows:

\[
P_k = \frac{1}{k!} \left( \frac{\lambda}{\mu} \right)^k \cdot P_0.
\]

where \( P_0 \) is determined as follows:

\[
P_0 = \sum_{k=0}^{C} \frac{1}{k!} \left( \frac{\lambda}{\mu} \right)^k + \frac{1}{C!} \left( \frac{\lambda}{\mu} \right)^C \cdot \rho \cdot \frac{1 - \rho^{D-C}}{1 - \rho}.
\]

After that we can easily calculate other properties of the system:

The average number of customers in service:

\[
ES = \frac{\lambda}{\mu} \cdot (1 - P_D).
\]

The average number of customers in the queue:

\[
EL = \sum_{l=1}^{D-C} l \cdot P_{C+l}.
\]

The average number of customers in the system:

\[
EK = ES + EL.
\]

We can easily derive and use formulas for calculation of further parameters of the system, for example, system use, the average waiting time of an element in the queue inside and outside the service system. Different probabilities of elements’ failure and idle times can be identified. After inclusion of other parameters in the mathematical model we can calculate further properties of the system, such as cost characteristics, duration of construction processes, environmental impact, fuel consumption, etc. After the introduction of all of the regularities in the

**Simulation software**

For the mathematical modelling and simulation, special software was used. The software allows an easy input of additional more precise parameters and coefficients into the model. A mathematical modelling was performed by the example of a construction phase "earth works". On the basis of the simulation results, an optimal design of machinery (excavators) for this task will be chosen from three possible options, as well as the optimal number of trucks for removal of soil. The decisive factor is the task fulfilment within a certain time with minimal financial costs. The volume of the task is constant and does not change. Other machinery, in this case the type of trucks (dumper), is predefined. The number of channels is based on the geographical conditions of the construction site, and, in our example, is given, \( N = 1 \). For simplicity, we will always choose the same kind of excavators for each channel.

![Fig. 4. Mathematical model of the system](image)

The whole mathematical model can be divided into three parts: input, core of the model, and output. See Figure 4. The mathematical model contains several important subsystems for the calculation of machinery failure and for the determination of economic parameters of the system; see Figure 5.

Further, the input parameters of the mathematical model will be described:

- construction process: excavation, construction pit, figure 1;
- volume of the task: \( 6000 \text{ m}^3 \), workability class: 3, loosening coefficient \( K_n = 1.25 \), the total volume of soil \( Q_{exc} = 6000 \times 1.25 = 7500 \text{ m}^3 \);
- parameters of auto truck (dumper) are shown in table 1.: dumper, body volume – 15 m\(^3\), the average travel time from site to landfill and back is 30 min., financial costs of machine operation: fixed costs – 3000 CZK, variable costs – 1000 CZK/hour, the maximum number of dumpers –
15; the failure rate is 2%/day; the average repair time – 2 hours; time of delivery to servicing machine is 2 minutes.

Working shift $T_s = 8$ hours per day, i.e. 40 hours per week.

Construction task has to be performed maximum in 2 weeks ($T_H = 80$ working hours, that is 4800 minutes).

The input parameters of proper excavators are described in Table 2. Most of the input parameters of machines are given by the manufacturer or calculated and averaged on the basis of observation and monitoring. An appropriate output per hour of an excavator, without the influence of random disturbances, according to (7) is greater than

$$P_{\text{app}} = \frac{7500}{80} / 1 = 93.75 \text{ m}^3/\text{hour} \quad (7)$$

Basic time unit is a minute.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucket volume, [m$^3$]</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Average duration of working cycle, [min]</td>
<td>0.83</td>
<td>0.67</td>
<td>0.625</td>
</tr>
<tr>
<td>Average hourly output, [m$^3$/hour]</td>
<td>100</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Fixed costs, [CZK]</td>
<td>5 000</td>
<td>7 500</td>
<td>15 000</td>
</tr>
<tr>
<td>Variable costs, [CZK/hour]</td>
<td>2 000</td>
<td>3 000</td>
<td>4 000</td>
</tr>
<tr>
<td>Probability of failure, [%/day]</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Average time of repair, [min]</td>
<td>60</td>
<td>80</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 2. Input parameters of excavator

The total average time of the truck working cycle for each variant without the influence of random factors, according to (9) is equal to:

$$T_{C1} = 40 + 2 + 15 \times 60 / 100 = 40 + 2 + 6 = 48 \text{ min.}$$
$$T_{C2} = 40 + 2 + 15 \times 60 / 120 = 40 + 2 + 5 = 47 \text{ min.}$$
$$T_{C3} = 40 + 2 + 15 \times 60 / 150 = 40 + 2 + 4 = 46 \text{ min.}$$

Hourly output of the truck for each variant according to (9) is the following:

$$P_{\text{truck} 1} = \frac{V_{\text{bucket}}}{T_{C1} \times 60} = 15 / 48 \times 60 = 12.50 \text{ m}^3/\text{hour}$$
$$P_{\text{truck} 2} = \frac{V_{\text{bucket}}}{T_{C2} \times 60} = 15 / 47 \times 60 = 12.77 \text{ m}^3/\text{hour}$$
$$P_{\text{truck} 3} = \frac{V_{\text{bucket}}}{T_{C3} \times 60} = 15 / 46 \times 60 = 13.04 \text{ m}^3/\text{hour}$$

The minimum number of trucks for maximum occupation of the excavator for each variant without the influence of random factors, according to (9) is:

$$P_{V 1} = N \times P_{\text{exc} 1} / P_{\text{truck} 1} = 100 / 12.5 = 8.0 \Rightarrow 8 \text{ dumpers}$$
$$P_{V 2} = N \times P_{\text{exc} 2} / P_{\text{truck} 2} = 120 / 12.77 = 9.4 \Rightarrow 10 \text{ dumpers}$$
$$P_{V 3} = N \times P_{\text{exc} 3} / P_{\text{truck} 3} = 150 / 13.04 = 11.5 \Rightarrow 12 \text{ dumpers}$$
Other calculations for determining the random effects will be performed in the simulation software\(^1\).

After the introduction of random values (machine failures) in the mathematical model, according to the simulation, the time of machine service extends:

\[
\begin{align*}
TN_1 &= 6 + 0.058 = 6.058 \text{ min.} \\
TN_2 &= 5 + 0.084 = 5.084 \text{ min.} \\
TN_3 &= 4 + 0.059 = 4.059 \text{ min.}
\end{align*}
\]

In the same way the intervals between inputs of elements into service will increase:

\[
\begin{align*}
TV &= TV_1 = TV_2 = TV_3 = 42 + 0.052 = 42.052 \text{ min.}
\end{align*}
\]

The total average time of the truck working cycle for each variant with the influence of random factors (failures) is equal to:

\[
\begin{align*}
TC_1 &= 42.052 + 6.058 = 48.11 \text{ min} \\
TC_2 &= 42.052 + 5.084 = 47.14 \text{ min} \\
TC_3 &= 42.052 + 4.059 = 46.11 \text{ min}
\end{align*}
\]

The described calculation is arranged in Tables 3, 4, 5 for each variant. Working cycles of the excavator and trucks are interdependent at the service place. Due to the random intervals between arrivals of vehicles, a queue to service will arise here. It is therefore possible to examine the dependences between the transport system and an excavator with the use of the theory of waiting lines\(^9\).

To make the optimal choice of machinery it is necessary first of all to determine other parameters of the queuing theory. The intensity of service is equal to:

\[
\begin{align*}
\mu_1 &= 1 / TN_1 = 1 / 6.058 = 0.1650709 \text{ min}^{-1} \\
\mu_2 &= 1 / TN_2 = 1 / 5.084 = 0.1966955 \text{ min}^{-1} \\
\mu_3 &= 1 / TN_3 = 1 / 4.059 = 0.2463661 \text{ min}^{-1}
\end{align*}
\]

The intensity of the input of elements into the queuing system:

\[
\lambda = \lambda_1 = \lambda_2 = \lambda_3 = 1 / TV = 1/42.052 = 0.023780 \text{ min}^{-1}
\]

The intensity of the system operation:

\[
\begin{align*}
\rho_1 &= \lambda / \mu_1 = 0.023780 / 0.1650709 = 0.14405974 \\
\rho_2 &= \lambda / \mu_2 = 0.023780 / 0.1966955 = 0.12089794 \\
\rho_3 &= \lambda / \mu_3 = 0.023780 / 0.2463661 = 0.09652335
\end{align*}
\]

After that we will calculate the basic characteristics of the system. According to the calculation, that to fulfil the excavation \(Q = 7500 \text{ m}^3\) within up to 80 working hours (4800 minutes) for the first variant 11 dumpers will be needed, the second requires 9, and the third requires only 8 dumpers. The initial period of the working cycle will be greater due to waiting in line for the service and will continually extend; the efficiency of the entire transport system with an increasing number of dumpers does not grow linearly, see Figure 5. In the last step of selecting the optimal system we will focus on the assessment of the cost parameters for each variant. The optimal solution is a variant with the lowest total costs.

Calculation of the cost characteristics of the system is shown in Tables 3 and 4 for each variant. In Figure 7 the optimal set of machinery is evaluated. The calculation and the selection of an optimal system include the operational costs for the excavator and trucks. The total working time does not exceed 80 working hours.

In Table 3 it is shown that the total costs of trucks for the third variant are the lowest of all options and are equal to 664,000 CZK, respectively 89 CZK per 1 m\(^3\) of excavation. Table 4 shows, that the total costs of the excavator by the first variant are the lowest of all and are equal to 165,000 CZK, respectively 22 CZK per 1 m\(^3\) of excavation.

On the basis of 8 we choose the second variant. For the task fulfilment, the second variant is chosen: excavator with output of 120 m\(^3\)/hour and 9 trucks for the transport of soil.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trucks, [-]</td>
<td>11</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Fixed costs, [CZK]</td>
<td>3 000</td>
<td>3 000</td>
<td>3 000</td>
</tr>
<tr>
<td>Total fixed costs, [CZK]</td>
<td>33 000</td>
<td>27 000</td>
<td>24 000</td>
</tr>
<tr>
<td>Variable costs, [CZK/hour]</td>
<td>1 000</td>
<td>1 000</td>
<td>1 000</td>
</tr>
<tr>
<td>Total variable costs, [CZK]</td>
<td>880 000</td>
<td>720 000</td>
<td>640 000</td>
</tr>
<tr>
<td>Total costs, [CZK]</td>
<td>913 000</td>
<td>747 000</td>
<td>664 000</td>
</tr>
<tr>
<td>Costs per 1 m³ of excavation, [CZK/m³]</td>
<td>122</td>
<td>100</td>
<td>89</td>
</tr>
</tbody>
</table>

Table 3. Calculation of costs characteristics of auto trucks system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of excavators, [-]</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total fixed costs, [CZK]</td>
<td>5 000</td>
<td>7 500</td>
<td>15 000</td>
</tr>
<tr>
<td>Variable costs, [CZK/hour]</td>
<td>2 000</td>
<td>3 000</td>
<td>4 000</td>
</tr>
<tr>
<td>Total variable costs, [CZK]</td>
<td>160 000</td>
<td>240 000</td>
<td>320 000</td>
</tr>
<tr>
<td>Total costs, [CZK]</td>
<td>165 000</td>
<td>247 500</td>
<td>335 000</td>
</tr>
<tr>
<td>Costs per 1 m³ of excavation, [CZK/m³]</td>
<td>22</td>
<td>33</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 4. Calculation of costs characteristics of excavator system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs of the auto trucks, [CZK]</td>
<td>913 000</td>
<td>747 000</td>
<td>664 000</td>
</tr>
<tr>
<td>Total costs of the excavator, [CZK]</td>
<td>165 000</td>
<td>247 500</td>
<td>335 000</td>
</tr>
<tr>
<td>Total costs, [CZK]</td>
<td>1 078 000</td>
<td>994 500</td>
<td>999 000</td>
</tr>
<tr>
<td>Costs per 1 m³ of excavation, [CZK/m³]</td>
<td>144</td>
<td>133</td>
<td>134</td>
</tr>
</tbody>
</table>

Table 5. Calculation of cost characteristics of the system „excavator + auto trucks“

**SUMMARY AND CONCLUSIONS**

To concentrate on reducing the costs of construction means to avoid unnecessary delays in construction, as well as unnecessary additional costs due to a poor technology or wrong mechanization. The aim is to minimize these problems or even entirely eliminate them. The one of the main aim of our research is to eliminate unnecessary delays and additional costs. The mathematical modelling in the special simulation software proved the applicability of the queuing theory for construction processes. In the case of the introduction of additional parameters into the system, the mathematical model will be closer to an actual construction process in reality. The model can include a variety of random factors, including climatic and geographic conditions. On the basis of the simulation results, a construction manager can justify a decision on choice of machinery according to various criteria.

The mathematical simulation should show that some variants of machines combination fail to fulfil the task under the given conditions, and some will not be optimal in terms of costs or other parameters, while other variants will be optimal from the view of costs required to fulfil the construction task. The mathematical simulation of the basic example showed that the first option fails to perform the task under the given conditions; the second variant proved to be optimal in terms of the costs of the construction task fulfilment. The simulation software allows us to look at the results in a graphical form or to export the data to other programs. The application of the queuing theory allows us to introduce into the system a waiting time for the servicing elements and to approximate the mathematical model to a real working task on site.

The application of queuing theory in the construction Industry is well known in the world and very wide and well described in the technical literature. But the first time, we use a mathematical modelling in the simulation software. The present study demonstrates that it is possible to model mathematically and technically the whole complicated construction process containing hundreds of constituent construction processes, with a number of simplifications, and then to perform various calculations and changes for an effective, efficient and long-term planning of construction. Of course, we cannot state that our model is flawless and absolutely accurate. It is therefore important to verify the results of the study under real conditions.

**References**


Laser Positioning System Using RFID-tags

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Purpose We developed a production system for performing renovation work with increased use of pre-cut and pre-fabrication elements. To develop this system, a faithful 3D-CAD model of an existing building was made using a 3D-laser scanner. The purpose of this research is to develop a method for positioning the pre-cut and pre-fabrication elements precisely and at short notice.

Method First, a 3D-CAD model for renovation was made using the point cloud data of an existing building measured by a 3D-laser scanner. Next, the ID-number and the attribute data of the elements of the 3D-CAD model were stored in a database. The database was then sent to the factory along with the fabrication design drawings. The RFID-tags were put on the corresponding elements in the factory. This system automatically identified the delivered elements by reading the RFID-tags, highlighting the appropriate elements of the 3D-CAD models, and it extracting the positions coordinates automatically. The coordinate data were sent to the automatic positioning system using the motor-driven total station developed by us; the workers were shown the positions by employing laser radiation. The coordinates of the positions were defined on each element and registered as individual information of the element objects. Thus, it is possible to obtain the position information of the elements by simply locating the element objects on the 3D-CAD.

Results & Discussion In our experiment we installed a dry wall in a room in an existing building. Our system helped in eliminating the marking process, and the wall could be installed using only pre-cut elements. However, some issues that need to be tackled in the future were revealed: (i) it might be impossible to point the laser to the position for an element if this position is in mid-air; (ii) since assembling is performed in a particular sequential manner, a method for searching and identifying a required element is needed.

Keywords: automation, renovation work, total station, 3D CAD, RFID tag, positioning

INTRODUCTION
On a construction site, the members and equipment are positioned based on manual marking performed using convex, plumb, and laser instruments after referring to the drawings. However, it is difficult to improve the working efficiency and accuracy because of the need for this manual work. In addition, there is a possibility of human errors because of the requirement of reading the drawing on site. In contrast, various information technologies such as the total station, 3D-CAD and GPS have been developed in civil engineering work1,2. The authors have developed a system that extracts the positioning data of members from 3D-CAD and positions them simply and accurately using the automatic laser pointing function of a motor-driven total station3. In this report, we provide a detailed description of the laser positioning system using an RFID tag and suggest future topics for this research by performing two experiments. These involve the installation of a partition wall in a room and piping work in an air-conditioning machine room.

CONFIGURATION AND FLOW OF SYSTEM
The system configuration is shown in Figure 1. The control system of the total station (TS Controller), 3D CAD viewer, and positioning system using an RFID tag (RFID Positioning System) are installed in a laptop computer. The laptop can communicate with the total station and RFID reader through a wireless LAN and Bluetooth.

The flow of this system is shown in Figure 2. First, a database of the members is assembled from the 3D-CAD model and sent with the drawings to the factory. Next, the members are fabricated and equipped with RFID tags. Their ID numbers are recorded in the database. The members are brought to the construction site and identified by an RFID reader, and the position data are extracted from the 3D CAD model. Finally, the total station points out the position using a laser.

DEFINING POSITIONING POINTS
In this system, the member objects are previously registered in the library, allowing the operator to create a design by locating the objects in 3D-CAD. Defining the positioning points to each object enables to give the coordinate data of the position by locating them. We previously proposed a method to create the marking data by locating the specific objects referring to the drawings. The method proposed in this paper makes it possible to save the work for making the data and prevents human errors.

As examples of positioning points, those for the members of a drywall partition, pipes, and ducts are shown below.
(1) Runner
The positioning points of a runner are on the surface of the frames because it is fixed directly to them. Therefore, the positioning points are defined as the center points of both edges considering the positioning activity.

(2) Stud
As shown in Figure 3(b), the positioning points of studs are defined as the points beside the runner on the floor because they are fixed on the runner at even intervals. The lines are scratched at the stud positions in the factory. The initial D in this figure is the setting value, which was 20 mm in the experiment shown below.

(3) Plasterboard
Plasterboard is set on the runner and studs, and generally the joint falls on the centerline of a stud. Therefore, the positioning points are defined as the corners at the bottom of the board, as shown in Figure 3(c).
(4) Pipe and Duct
Members of the equipment are also divided into two categories: the members set directly on the frames and those set using supports. The positioning points for the former are anchor bolts in most cases. On the other hand, the latter cannot be indicated using the laser because their positions are in the air. Therefore, the positioning points are defined as the positions of the supports fixed on the frames, which are the positions of the anchor bolts, as shown in Figure 4. This system would detect all of the supports attached to a pipe or duct in CAD, and extract the coordinates of the positioning points automatically.

**COOPERATION BETWEEN RFID TAG AND CAD**

**Database of members**
First, a database of the members is created. The members organized as a “Group” or “Module” are selected in CAD. Group indicates a unit that is to be brought to the site, while Module indicates a combination of members that will be assembled in a factory. An example of organizing a pipe module is shown in Figure 5.

The items of data include the ID number of the RFID tag, file name, group or module name, type, name, sizes, and order and delivery dates. The database is output in the CSV format and sent to the factory with the CAD data.

**Management of delivery of members**
RFID tags are placed on the members manufactured in the factory, and the ID numbers are recorded in the database of members. The database is sent to the site and loaded into the system. The system verifies that all of the members of the groups are brought to the site by reading the tags and records the delivery date in the database. At the same time, it indicates the area of the group by highlighting it in CAD.

**Extracting positioning data for members**
When a tag of an arbitrary member is read, the system recognizes it, along with all of the members of the same type and size, and shows the list. The operator is able to select one using one of three methods.

1. **Select manually**
   All of the relevant members are shown by highlighting. The operator then selects one manually.

2. **Select by designated direction**
   The system selects the member according to the designated direction and shows it by highlighting automatically.

3. **Select by free**
   The system selects the member nearest to the previous one and shows it by highlighting automatically.

**Positioning with total station**
The total station is an instrument that can calculate the 3D coordinates of a laser point by measuring the horizontal angle, vertical angle and distance. Using a motor-driven total station makes it possible to indicate any point using an inverse calculation. The coordinates of the positioning points of the selected members are in the form of CSV data. When the operator opens the data file and operates the pointer
through the TS controller, the total station points to
the position with the laser automatically. Here, in a
case where the position of the surface radiated with
the laser is different from the drawing, the position of
the laser pointer is different from the target. There-
fore, this system has a function to correct the posi-
tion by measuring the coordinates of the laser point.

**FIELD TEST**

**Applied to installation of partition wall**

(1) Work Summary

We applied this system to the installation of a parti-
tion wall in an office building, which is a reinforced
cement concrete structure. An L-shaped drywall partition
would be installed in a meeting room. The picture of
the room before the installation and the top view of
the partition wall are shown in Figure 7. The mem-
bres of the wall were the runners, the studs, and the
plasterboard.

(2) Result of Test

First, all of the members were precut based on the
drawing. As shown in Figure 8, RFID tags were
placed on the members, and their ID numbers were
recorded in the database. Next, the members were
installed in the order of runner, stud, and plaster-
board. When an RFID tag was read as shown in
Figure 9, the system recognized the member and
sent the positioning data to the TS controller to indi-
cate the positioning point with the laser. The operator
installed the member according to this indication, as
shown in Figure 10.

The partition wall was installed as shown in Figure 11.
It was impossible to indicate the positioning points of
the runners, as shown in Figure 3(a), which would be
installed under the beams because they were longer
than the width of the beams, as shown in Figure 12.
The positioning points for the runners should be defined with a consideration of the surface attached to the frame.

**Application to piping work in air-conditioning machine room**

(1) Work Summary
We applied this system to the renovation of the equipment in the air-conditioning machine room of the office building. The draft is shown in Figure 13. In this test, the system was applied only to the piping.

(2) Result of Test
As shown in Figure 14, the members were manufactured in a factory, and RFID tags were placed on
them. First, the tags on the support members (the hangers) were read, the anchors were set directly on the positions indicated by the laser of the total station as shown in Figure 15, and the hangers were set on them. Next, the tags on the pipes were read, the total station indicated the anchor positions of the hangers (as shown in Figure 16), and the operator set them according to the indication. The pipework installed using this system is shown in Figure 17. All of the members could be set just as shown in the draft.

Determining future research topics
We initially considered that it might be possible to omit the marking process because the members are installed directly according to the laser indication. However, we found that it was necessary to mark the positioning points for the members with multiple points such as the runner of the partition wall because it is impossible to indicate multiple points simultaneously. We think that it is necessary to consider a different method for indicating points in order to omit the marking, for example, indicating multiple points quickly and repeatedly.

In addition, it is impossible to extract the member you want to install. Considering the fact that an installation generally has a specific order, we think that the proposed method of extracting the intended member and of packing and transporting the members is appropriate.

CONCLUSION
In this work, we described a method for positioning construction members accurately and reasonably by defining the positioning points for member objects and connecting the objects to the members using RFID tags in a positioning system with a total station. In addition, we demonstrated the effectiveness of this system and suggested future research topics for this system through two field tests.
References

Note
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Information technology supporting daily activities of seniors

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Purpose Currently, ICT-products play an important role in improving the quality of life and matching user needs in the information society. The ICTs and embedded tools in public services improve users' autonomy, safety, self-realization, social inclusion by facilitating communication between family members, carers and persons with disabilities, etc. Our research team participated in the 6FP-project called MonAMI1 devoted to the development of accessible and usable services for seniors that can be delivered in mainstream systems and platforms.

Method The MonAMI technology platform was derived from standard technologies and has a unique architecture based on the Residential Gateway (RG-PC with touchscreen), OSGi-platform2 (the dynamic module system and service platform for JavaTM), sensors and actuators dedicated to monitoring and control of the senior's households. Sensors and actuators use open technology networking such as wireless ZigBee combined with wired 1-wire nodes. MonAMI-system and services provide local and remote monitoring, local and remote actuating, detection and alarm notifications of potential dangerous situations. Monitoring services monitor various household's parameters. Data about room temperature, luminosity, motion detection, usage of electrical appliances are sent automatically to the RG and processed in real time. In case of unusual behavior detection, the alarm is triggered to alert the responsible person, e.g. the carer. Light, shutter, and electrical appliances actuators controlled automatically or by individual depending on setting are used to facilitate seniors' everyday life.

Results & Discussion The technology and developed services were firstly tested in a laboratory environment with prospective users and their carers. Later, 20 participants living alone in their households were chosen for a three-month trial where different experimental testing was running under real conditions. We obtained information about usefulness of each service and device, advantages and deficiencies of the system, participant’s feelings about new technologies and so on. The system has helped the majority of participants in terms of increased safety. Carers confirmed the unloading of the responsibility affected their daily life. Results were used for the design set-up of the new research project; at the same time we continued supporting the municipality by running MonAMI-services for the test group of seniors in the MonAMI-project after completion.

Keywords: ICT, monitoring, automation, household, elderly

INTRODUCTION
As the ICT is growing rapidly and it is becoming an integral part of daily life e.g. in the way of communication, obtaining of information, data handling, etc., there is a potential of increasing social exclusion. The most vulnerable are groups of elderly people and people with disabilities because of their economic and health status. They are exposed to the risky situation of excluding from use of new technologies due to the low availability, accessibility or literacy of ICTs usage. Services and technologies based on ICTs designed for elderly and people with disabilities offered as a mainstream products are insufficient. One from our objectives has been to demonstrate that services and technology platform derived from standard technologies, developed in MonAMI project, is accepted by elderly and they are supportive in their daily activities.

DESCRIPTION OF SYSTEM - MonAMI PLATFORM
The idea of MonAMI platform was to construct technology platform which is derived from sub-systems of standard technologies. The platform is assigned to deliver services, which integrate reliable wireless (ZigBee technology), Self Organizing Networks, wired networks (1-wire technology), user friendly devices for interaction, wearable devices and components for health monitoring. Sensors and actuators are connected to the Residential Gateway, where the main logic of the system is running basically dedicated for evaluation and determination of next action. Due to the usage of OSGi4AMI hardware implementation of the sensors and actuators is transparent to the services. They appear in the system as software objects with predefined methods and functionality. Residential Gateway could be any computer with x86 architecture and Java™ technology support. Its
role is to centralize the MonAMI services in one point which enables services to share the same resources and afford opportunity to create extended services. The user can interact with MonAMI system via intuitive user interface (UI). In our project and trials we have used as the RG Asus EeeTop - touch screen computer. The UI may, however, run remotely on another ICT device such as PDA, smart phone, tablet, another computer. The communication between RG and user interface is established with predefined protocol. We have used UCH protocol which is based on HTTP and socket communication. The Universal Control Hub was developed within the scope of the 6FP project i2home and is provided by the Universal Remote Console Consortium.

One part of system is also Social alarm, which can dial up responsible person in case of risky situation. This service is provided by digital carephone unit which offer to the user a high quality voice-to-voice connection in dangerous situation. It uses a standardized protocol called SIP which is a world standard protocol used to establish speech and video uplink via a broadband connection. In addition to the voice-to-voice alarm calls it provides communication layer between beneficiaries and carers for platform in MonAMI system.

ZigBee technology
Reliability and usability are achieved by using different communication protocols and path ways. ZigBee communication protocol is created by Zigbee alliance. Zigbee alliance is an association for companies working together to develop this standard. Zigbee technology can be installed for variety of applications such as smart houses, intelligent buildings and in industry. Zigbee is based on IEEE 802.15.4 standard which defines physical and MAC layer for low cost and power for personal area network. The physical layer is working on three frequencies - 2, 4 GHz in most countries, 868 MHz in Europe and 915 MHz in USA and Australia. All of these frequencies use DSSS (Direct sequence spread system) access and two types of modulations B-PSK (binary phase shift modulation – for 2.4GHz) and O-QPSK (offset – quadrature phase shift modulation – for 868 a 915 MHz).

ZigBee MAC Layer is defined in standard IEEE 802.15.4 and defines two types of devices (nodes): FFDs and RFDs. On FFD (fully functional device) is implemented full set of functions which are provided by MAC layer and can communicate with others FFDs and RFDs. One of the FFDs device is always network coordinator. Coordinator sends beacons and provides synchronization and joins services. RFD (reduced functional device) acts like end device, it can only communicate with nearest FFD.

ZigBee networks offers 3 types of topologies – star, mesh and tree. In star topology master-slave technology is used, where one off the FFDs is PAN coordinator = master. Other devices act like slaves (no matter if its RFD or FFD type of device). In mesh and tree topology is coordinator too and its function is to start network with initial parameters.

ZigBee alliance created standard which defines higher levels of protocol. According to net-work layer provide services fort routing and “hop” network. On this level standard defines three types of devices FFD and RFD as end devices (compatible with IEEE 802.15.4) standard and Router. Router is FFD which provides services for routing. One FFD is coordinator and manage whole network. Interface between NWK (network layer) and the application layer (APL) is Application support sub-layer (APS). Application layer in general consists of three elements: APS sub layer, ZDO (ZigBee device object) and application objects designed by manufacturers. Application framework is the environment in which application objects are hosted on ZigBee devices – maximum 240 object can be defined. This system allows to objects discover each other and organize them in to a distributed network and also allows devices to connect or leave the network.

Wireless ZigBee sensors and actuators
All chosen devices used in MonAMI platform to equip households of elderly are commercially available on the European market.
power and communication delivered over the serial protocol, 1-Wire devices are unmatched in their ability to provide key functions to systems where interconnect must be minimized.

The 1-Wire® Net, sometimes known as a MicroLAN is a low-cost network based on a PC or microcontroller communicating digitally over twisted-pair cable with 1-Wire components. A 1-Wire Net based system consists of three main elements: a bus master with controlling software, the wiring and associated connectors and 1-Wire devices. The 1-Wire net allows tight control because no node is allowed to speak unless requested by the master, and no communication is allowed between slaves, except through the master.

The 1-Wire® communication protocol can be generated with an IO pin on a microprocessor; however, care must be taken to provide the correct timing and proper slew rates to create a reliable 1-Wire network. Uncontrolled slew rates can severely limit the length of a network and create sporadic behavior.6

1-Wire sensors
The 1-Wire sensors were mainly used due to stability of network during transmission of data. Second approach was dedicated to comparison of stability, reliability and adaptability of using the sensors. Wire network required more building changes (wires, adapters, new outlets and sockets) as wireless technology. It becomes easier to manipulate or restart in case of electricity outage. Wire technology also has to be constructed from base as prototypes designed to individuals. In contrast to wireless technology, sensors can be bought from market.

![Gas and smoke sensors based on 1-wire technology](image)

OSGi platform and OSGi4AMI
The main benefit of OSGi platform is modularity in Java programming language, which allows applications to be created from small, reusable and interoperable components. Each component, called bundle has its own life cycle (installation, start, update, stop, and uninstallation). A transition from one state to another is done without the need to restart the whole system. This significantly improved the development phase, where different sites were providing different application components and the whole implementation process was done in parallel.7

OSGi4AMI represents a reference point for all developers of the MonAMI system. It is a common interface framework developed as an open source technology (accessible at Source Forge)8, which enables through provided ontology the interaction between MonAMI Framework modules. This ontology defines the concepts used by MonAMI software modules of RG. The mechanism of the OSGi services layer enables registration, searching and notification functionality of new implemented services.

TRIALS IN LABORATORY ENVIRONMENT
The MonAMI platform and services were build and running at first in “Living labs” (prepared as fully functional household with typical rooms), where researchers designed and tested architecture, placement, devices and other parameters needed for installation in to real life. Afterwards, for services was created intuitive and interactive interface for interaction with users. Also interface for technician and careers to set up and individualize services were prepared. Laboratory is equipped with all developed interfaces, devices and actuators to show all possibilities of services for users which are interested in such type of services.

In our laboratory we are able demonstrate that developed services are technically feasible and usable for seniors and also show to users how these services can improve the quality of their life. Users and their carers provided a good feedback to researchers especially in the content of services and user interface. Researchers collected their feedback in several stages of project period (1- before full testing in homes, during laboratory testing, 2- after first two weeks of testing at homes, and 3 – on the end of testing at homes).

Researchers have tested two types of communication in MonAMI. Wireless, based on ZigBee technology and wired, based on 1-Wire technology.

TRIALS IN SENIOR’S HOUSEHOLDS
Living Scale Field Trial was carried out in the homes of elderly and disabled people. Users were chosen in cooperation with House of Seniors. Selected users had to fulfill including criteria. These included age (seniors above 65 years), life situation (living alone) and health conditions (with disabilities: reduced mobility, memory problems, low vision, hearing problems). Finally 20 participants were choosed according these eligibility criteria. User’s carers participated also in project trials and they provided feedback about their experiences with services during the trials.

Testing period started with pilot testing in two households. They have been equipped with Telco technology to achieve remote control of service installation from research centre. It enables installation of required services and also correction of failures or
problems with services. After pilot was running correctly, testing started with installation into other households.

**Questionnaires and interviews**
During trial period data were gathered by questionnaires. Questionnaires were filled by users and also by careers. In the beginning, before LSFT trials started the Baseline structured questionnaire were completed. These interviews were focused on the social-demographical data and health status of user participated in LSFT.

In the middle of testing phase Mid-Term checkup questionnaires were applied. The mid-term face-to-face interviews included filling the semi-structured questionnaires, where the first data about the accessibility, acceptability and suitability of the services were collected. The interviewer discussed each service enabled in the user’s households. They evaluated satisfaction with each particular service, and questions how the services fitted into their daily lives. Also, the interfaces used in trial were discussed. The mid-term interviews were time demanding whereas each particular service installed in the user’s household was discussed with both user and carer.

The post-trial instrumentation consisted primarily of in-depth, semi-structured interviews about users’ perceptions of the benefits of the services. The research team visited each user again to perform face-to-face post-trial interview to collect detailed valuable data about the usefulness of the services and their contribution to the independence, health and well-being, social networking, safety-security, acceptability and e-inclusion.9

**Services used in LSFT**
Tested services were designed and based on daily needs of seniors and they represent modular system of services, with possibility install chosen services according the real needs and requests of end-user. These services are based mostly on if-then rules. The condition part combines information from several devices and technological services. The conclusion part is based on a combination of functional services and devices.

Services designed and developed in project were divided into three main categories according the aim of use.

**Monitoring** where beneficiary is able to monitor different parameters e.g. temperature, appliance usage, presence etc. locally or remotely. Monitoring is done through web based UI, so carer can also check if for example beneficiary is present at home if it is expected.

**The Remote control** is service mainly aimed for beneficiary; they could turn on/off lights or appliances. The lights are turned on automatically also in case of detected presence when the light threshold is below predefined threshold (this service is called LightSURE and for the majority beneficiaries is used in hall and toilet space).

**Services for Alarm notification** are dedicated to inform carer about various types of alarms e.g. smoke and gas leak danger, presence is detected in dangerous zone when not expected, social alarm etc.

All services are configurable and adaptable according the users’ needs and the configuration and adaptation was made by technical staff during trials. The parameters for configuration purposes were gained from questionnaires filled with users before the start of trials.

Services used in household trials focused on user safety:
- GasSURE and SmokeSURE – services dedicated to monitoring dangerous level of smoke and gas concentration.
- AppSURE – switching off an electric device if this device is in usage for more than a predefined time or energy spent. It is useful when the user has forgotten to switch off e.g. iron, hot-plate etc.
- ZoneSURE – if motion sensor recognizes /do not recognizes a user activity during a predefined time in predefined area, responsible person is informed about this situation.
- TempSURE – sends an alert or trigger an alarm if temperature is for longer time lower or higher then predefined threshold.

Not all services were installed in each household. Before installation of the system some beneficiaries refused particular services, because they considered them unnecessary or they required hard installation in their living environment.

![Fig.4. User in LSFT trials](image)

**RESULTS AND DISCUSSION**
Testing was done in three countries in Europe (Sweden, Spain, and Slovakia) due to comparison in cultural, political and legislative issues. We installed and tested services in 20 households located in the area...
of Košice city in Slovakia for seniors living there alone. During trials in households several technical problems occurred from the beginning. The information from social alarm was sent to informal carers, mainly family relatives. The CareIP social alarm had problem with SIP server on the side of internet provider. The communication was canceled after 20 seconds. To solve the issue we had changed SIP implementation and server due to specific condition. In some households happened that users turned off the system or disconnect devices. Intentional shutdown was caused because they were unsatisfied with one particular service and this was for them the fastest way to solve their problem or the unintentional shutdown of the system was often caused by accidental removal of the RG plug.

SmokeSURE was mostly appreciated safety service with 5 successful uses while testing. Only once time false alarm was recognized. The false alarm was caused by fault of device which was replaced by new ones.

Configuration of user interface was underestimated from our side, since the carers evaluated it as rather complex and should be improved in future. Because of not so high computer literacy of middle-age people in Slovakia, and this group created the largest number of unformal carers – children of beneficiaries.

Based on Post-Trial questionnaire we can conclude that users were satisfied with choosen services because they felt safer and also carers were satisfied. Users evaluated as the most useful and necessary services ZoneSURE, ConnectSURE (social alarm, which connects the user to carer through CareIP, who could remotely check how dangerous the situation is) and AmiPAL a reminder of the events like taking pills, visiting a doctor, etc. On the other hand they wanted also other services, which were not included in project like video doorman.

Comparison between wire and wireless technology brings remarkable notices. Wireless technology is reliable and more adaptable for using in regular senior’s household. Sensors can be mounted just by placing on specified spot, in case of outage or restart they easily find way to connect master slave or network coordinator. All these positives are underlined with low electricity consumption.

The experience from the whole trial is very helpful in future development of such services in our region. MonAMI field trial opens discussions with local stakeholders leading to formulation of the new tasks in social area like demanding the creation of an effective platform for the Social alarm service in Košice city. Activities within the frame of the project has pushed the Municipality of Košice to facilitate the discussions about the care for elderly and disabled based on ICT.

Project and results from trials with seniors accelerated cooperation between local partners and stakeholders to prepare other solutions and start to implement these solutions into business. From the user’s point of view, they were satisfied mainly in the area of safety and possibility to be monitored in secure and unobtrusive way and also they highly appreciated to manage contact with other people, children or seniors.

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References

“The Desirable Scale”: Weighing social quality of assisted living facilities

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Purpose In order to age-in-place, Dutch older adults have been housed in Assisted Living Facilities (ALFs) for over 25 years. Here they live independently but can rely on services and care facilities. The size of these ALFs ranges from 30 up to 300 residents. They are often considered to be outdated. Nevertheless, they continue to be built but their character is changing by housing a greater mix of people. In contrast with the field of housing and care for dementia, the impact of scale on social quality of housing has not yet been explored. This paper discusses the relationship between scale, social interaction, the facilities offered to the tenants, and the perceived quality of living conditions.

Method We reviewed the literature on concepts of scale, mix of functions and groups, and quality of social environment of housing for the elderly. After this desk research, a strategic selection was made from the database of the Expertise Centre Housing-Care. This paper presents the results from the multiple case study of the selected 24 projects. Observations were made on each of them. Around 196 inhabitants, 48 initiators, and 48 professionals were interviewed using a narrative method, qualitatively analysed in ATLAS ti.

Results & Discussion The projects were far more mixed than presumed, resulting in two contradictory findings: a positive influence on social interaction and informal care but a negative influence on perceptions of confronting a more care-demanding future. Government and initiators intentionally presume informal care: healthy elderly support other groups. This is directly related to the mix of the independency among inhabitants. Where present, this mix encourages social interaction and quality. However, due to reductions by government and changing demands for housing, more people can age at home. This results in more limited mutual informal care and so undermines the concept of Assisted Living Facilities. Depending on the situating, scale influences this precarious balance directly: small-scale projects are more appreciated in villages, large-scale projects in cities. Safety experience -an important social quality of housing- is better assured at small scale. Regarding social interaction, in villages there is more informal contact and social cohesion; this social control has both positive and negative effects. In city environments however, the lack of the negative aspects of social control are a major factor in appreciating the large scale. Moreover, a good mix of people is more easily obtained in a large scale setting: diversity, liveliness, and activity are all more appreciated in cities. Ultimately, aggression within social relations has a strong negative influence on social activity and bonding: elderly avoid communal activities within the ALFs. The influence of scale on relational aggression will be analysed in the final phase of this research during the first half year of 2012.

Keywords: social quality of housing, scale, group mix, assisted living

INTRODUCTION Housing and care for the elderly in the Netherlands are changing constantly. In the last decades, previously appraised care in elderly homes has been substituted by home care. Nursing homes that provide care to the very old in a prolonged, systematic and multidisciplinary way, in a intramural setting, have partly been replaced by small-scale housing facilities. Since the eighties, vital elderly have been housed in assisted living facilities, preferably in areas with integrated neighborhood services. The goal of these changes is to support aging in place with better social quality of housing and to reduce the costs.

Assisted living facilities (ALF) have been built since 1983. They accommodate elderly people that live independently but can rely on care and services within the project when needed. The latest survey on ALFs goes back to 2005. Nowadays ALFs are often considered to be outdated because of the need for cutbacks on care and the strong ‘care mark’ that discourages younger seniors to choose for this concept. This may explain why ALFs are less popular as a research subject. Nevertheless, they are still being built and, more importantly, they are changing in character since a larger variety of target-groups is being housed nowadays, including both people with a low need for care and with a very high need for care. Present definitions should be stretched to cope with this change, see Fig. 1. An important question is whether an extensive mix of target groups leads to more or less integration and social quality of ALFs.
Within the field of care for dementia, studies on scale\(^2\) showed that small scale group living has a positive effect on work satisfaction of professional caregivers and, to a somewhat lesser extent, on wellbeing of residents. Inhabitants living in projects with less or smaller groups are more active and go outside much more, but are visited less frequently. These results have led to revaluation of small scale in legislation. Objections arise as well, pointing at the less opportunities to find favourite tenants and the adaptations to this new approach for the staff\(^8\).

The impact of the physical scale of assisted living facilities on social quality of housing – directly and indirectly via its impact on the number and heterogeneity of tenants - has not yet been explored. Initiators have to decide on the basis of previous experiences, intuition and good intentions, and are usually guided by policy letters and a focus on exploitation costs. Due to a lack of data “evidence based choices” using quality indicators are not well possible. For this reason a PhD-research project was started on “The desirable scale”. In addition to a scientific thesis with sound conclusions and recommendations to support evidence based decision making, a web based tool and a hardcopy atlas showing findings and best practices of small, medium and large projects will be produced to contribute to this end.

Preliminary interviews showed that many initiators of ALFs are lacking knowledge about the optimal scale of the facility, which groups should be accommodated regarding to age, need for care, and social origin, and which supporting facilities should be included if not present nearby. Generally, the aim is to establish maximum quality, but regulations and budgets create tight boundaries. Besides decision making is often supply driven and not primarily directed at demands and user participation.

On the basis of a review of literature and these preliminary interviews a conceptual model has been developed, that connects the physical scale of ALFs with group mix and social quality (Figure 2).

Furthermore the context is assumed to affect both decisions on scale and group mix and social quality as well. Furthermore it is assumed that the scale also affects the number and capacity of facilities and as such also the social quality of living in an ALF. These connections will be explored in another paper.

**Scale and social quality of housing**

Scale is an important variable in management theory as well as in architectural theory. For this study both disciplines are relevant. From management theory three concepts of scale that were introduced by De Groot\(^9\) are being studied: the physical, the structural, and the mental scale. The physical scale is the number of social and spatial units. The structural scale is the scale of the organisation process, in this case the process of care and service. The mental scale is the cultural pattern and the emotional bond of a group, in this case the inclusion or exclusion of target groups. Of these three concepts, physical scale is the independent variable, whereas structural scale and mental scale are perceived as intermediary variables that are affected by the physical scale and affect social quality of housing.

The architectural theorist Boudon\(^10\) defines scale as the ratio between a building and an element, and proportion as the mathematic expression of the mutual ratio between elements. Ching\(^11\) states that scale alludes to the size of a reference. He defines generic scale as the size of an element in comparison to the size of other elements in its context. In line with these theories, three concepts have been defined for this study with regard to the measurement of physical scale: the external, relative, and internal scale. The external scale, comparable with the generic scale of Ching, refers to the size of the service area of the ALF. The relative scale is the size
in comparison to other projects. Finally, internal scale, similar to proportion, is the partition with respect to internal groups.

Social quality of housing is related to existing definitions of quality in general and quality of housing in particular. Van der Voordt\textsuperscript{12} refers to a widely used definition of quality as the extent to which a product fulfills the requirements set for it. In architectural theory Alexander\textsuperscript{13} defines a ‘central quality’ in each city or building, which is on the one hand objective and precise, but on the other hand not exact at all, mentioning liveliness, flexibility, wholeness, comfort, safety. Zwart\textsuperscript{14} distinguishes the building quality and the quality of housing and decomposes both in the technical and economical quality on the one hand, and the functional, social, psychological and cultural quality on the other hand. Finally de Vreeze\textsuperscript{15} defines social, esthetical, and technical quality, which is very much in line with the Vitruvius concept of utility (Utilitas), beauty (Venustas), and reliability (Firmitas).

For this study we define the social quality of housing within an assisted living facility as the quantity and quality of social interactions between inhabitants and groups, the variety in leisure and activities, and the degree of safety and experience of being connected. The assumptions concerning physical scale and social quality of housing are:
- in general, small scale is preferred because of the more homelike situation and tailor made solutions
- large scale will benefit care and services, social interaction, diversity in activities and leisure and will support a larger group mix
- concerning the social quality of housing, the desirable scale is different in a village than in a city.

Mix of groups with different levels of care need
The mediating variables deduced from preliminary research were mix of groups with different levels of care need and level of facilities. In this paper the level of facilities is not elaborated. Group mix has a scale-related influence. For example, regarding housing for people with dementia, quality of life on the one hand, and the availability and variety of staff and activities on the other hand are directly influenced by the physical scale of the accommodation\textsuperscript{7}. In the last fifteen years, more target groups have been housed in assisted living facilities: elderly people with a higher need for care like dementia or a somatic problem but also younger people with a mental handicap (CBZ, 1998-2010). On the other side of the spectrum, groups without a care need are integrated and as such reduce the character of a care based housing concept (i.e. Malburgstaete, Arnhem; Meulenvelden, Doetinchem). Both developments are easily explained from a social integration point of view, a notion that has been incorporated for a long time in Dutch social housing\textsuperscript{10} and is stimulated by the government to avoid strong spatial segregations\textsuperscript{17}. Looking at integration of groups, we distinguish the principles of bonding social capital, the forces of alliance within a group, and bridging social capital, connections towards other groups. If a complex or facility is built with a focus on supporting social security, this can result in a ‘gated community’\textsuperscript{16}. Bonding capital is dominant and bridging capital is lacking. According to research of Holt-Jensen\textsuperscript{18}, the tipping point in integration of new groups in a neighbourhood is around 7%; will this be similar in an assisted living facility? Housing severe care demanding groups is even more complicated, see the studies of Duyvendak on integrating people with psychiatric problems\textsuperscript{19}. On the scale of the neighbourhood he detected strong believers in the curing side of integration and those who try to avoid confrontations and conflicts. The influence of the social and physical environment on people’s ability to cope with complex environments is larger when the competence of an individual is smaller, known as the environmental docility hypothesis of Lawton\textsuperscript{20}. Jacobs\textsuperscript{21} states that four factors are crucial for urban diversity: several mixed primary functions; dense pattern of streets; mix of age and condition of buildings, and sufficient concentration of inhabitants.

For the partition of groups in this research we looked at age, level of care need and composition of household. For the distinction of levels of care need (from no care till nursing home level) we used the definitions of Dutch legislation (AWBZ), TNO Health Assets, and the database Assisted Living Facilities of the Expertise centre housing and care (KWCZ), see Table 1.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Profiles</th>
<th>Groups database KWCZ</th>
<th>Groups in this research</th>
</tr>
</thead>
<tbody>
<tr>
<td>psycho geriatric patients</td>
<td>profile dementia</td>
<td>people with dementia</td>
<td>people with dementia</td>
</tr>
<tr>
<td>mentally handicapped</td>
<td></td>
<td>people with a mental handicap</td>
<td>people with a mental handicap</td>
</tr>
<tr>
<td>psychically handicapped</td>
<td></td>
<td>people with a physical handicap</td>
<td>people with a physical handicap</td>
</tr>
<tr>
<td>sensoric handicapped</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>somatic patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>psychiatric patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>elderly with psychiatric problems</td>
<td></td>
<td>people with psychiatric problems</td>
<td>people with psychiatric problems</td>
</tr>
<tr>
<td>elderly with few or no limitations</td>
<td></td>
<td>elderly</td>
<td>elderly</td>
</tr>
<tr>
<td>all (other) districts inhabitants</td>
<td></td>
<td>families</td>
<td>families</td>
</tr>
<tr>
<td>starters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>juniors</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Different levels of care need

In this paper we will test the following hypotheses concerning group mix and social quality of housing:
- groups with a lower care need will easier and better
mix with vital elderly than groups with a high care need
- a limited group mix will have a positive effect on feelings of safety and social cohesion and therefore on the social quality of housing¹⁸
- a group mix with not easily integrating groups beyond a certain “tipping point”¹⁸ will have a negative impact on the social quality of housing
- as a result, there is an optimal group mix concerning the effect on social quality of housing.

METHODS
The PhD-study is split in a desk research and a multiple casestudy. The desk research was used to get a view of the variety of ALFs regarding their physical scale, group mix, level of facilities and the influence of legislation and financing on these variables, and to analyse the connections between scale, mix of tenants and level of facilities. This paper focuses on the second part of the research i.e. the multiple case study. The sample was selected from 197 projects that are included in the Assisted Living Facilities databank of the Expertise Centre Housing and Care (KCWZ) and were built in the period 1998-2010. Primary criteria for selection were a variety regarding physical scale - (extra) small, medium and (extra) large – and a variation in group mix: 55+ with no or modest care need, mixed with higher care need, and mixed with higher and no care need (Table 2). To establish data triangulation, in each project both inhabitants, staff members, and initiators were interviewed. Besides, we conducted non-participating observations by walk-throughs, using an observation protocol. A narrative method was applied in the interviews to get more reliable information on the experience of the social quality of housing. The number of interviewed inhabitants should be approximately 30 in each level of the strategic selection (both rows and columns in Table 2) to reach saturation²⁵.

In this paper we will discuss the findings from a qualitative analysis of the interviews and our own observations. In another publication we will connect the qualitative data with the quantitative data.

RESULTS
From March 2011 until January 2012 all 24 projects were visited and studied. Two projects were slightly older than the criterion ‘new build after 1997’: ‘t Derkshoes (1995) and Bergweg (1996). Being advanced at that time and representative for the generation of ALFs, we did analyze them any way. Three projects turned out to be partly new build and partly expended: Mercator (1999), Huize St. Francisus (2000), and Huize ter Leeu (2006).

The intended range of physical scale was fulfilled as well as the intended variety in location. The variety in

Table 2. Optimal strategic selection, number of projects, and interviews per stakeholder group

<table>
<thead>
<tr>
<th>Physical scale in relation to group mix</th>
<th>(extra) Small &lt; 80</th>
<th>Middle 81 - 130</th>
<th>(extra) Large &gt; 131</th>
</tr>
</thead>
<tbody>
<tr>
<td>55+ with no or modest care need</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
</tr>
<tr>
<td></td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
</tr>
<tr>
<td></td>
<td>2 staff members</td>
<td>2 staff members</td>
<td>2 staff members</td>
</tr>
<tr>
<td></td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
</tr>
<tr>
<td>mixed with higher care need</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
</tr>
<tr>
<td></td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
</tr>
<tr>
<td></td>
<td>2 staff members</td>
<td>2 staff members</td>
<td>2 staff members</td>
</tr>
<tr>
<td></td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
</tr>
<tr>
<td>mixed with higher and no care need</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
<td>&gt; 4 projects:</td>
</tr>
<tr>
<td></td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
<td>6-8 inhabitants</td>
</tr>
<tr>
<td></td>
<td>2 staff members</td>
<td>2 staff members</td>
<td>2 staff members</td>
</tr>
<tr>
<td></td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
<td>1-2 initiators</td>
</tr>
</tbody>
</table>

Table 3. Type, number and indicators of the codes

In this paper we will discuss the findings from a qualitative analysis of the interviews and our own observations. In another publication we will connect the qualitative data with the quantitative data.

<table>
<thead>
<tr>
<th>Code type</th>
<th>Number</th>
<th>(example of the) Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biographic information</td>
<td>8</td>
<td>Civil status, age, children, vitality,...</td>
</tr>
<tr>
<td>Research variables</td>
<td>6</td>
<td>Scale, group mix, level of facilities, social quality of housing, context.</td>
</tr>
<tr>
<td>Indicators</td>
<td>22</td>
<td>Physical scale, ...mix with..., legislation,..., social interaction,...</td>
</tr>
<tr>
<td>Control variables</td>
<td>4</td>
<td>Functional; economic; technical and esthetic quality.</td>
</tr>
<tr>
<td>Quality</td>
<td>4</td>
<td>(Non) satisfied, problem, solution.</td>
</tr>
<tr>
<td>Personal radius</td>
<td>3</td>
<td>Own, next, far</td>
</tr>
<tr>
<td>Environmental radius</td>
<td>4</td>
<td>Dwelling, project, street, village, city.</td>
</tr>
</tbody>
</table>

In this paper we will discuss the findings from a qualitative analysis of the interviews and our own observations. In another publication we will connect the qualitative data with the quantitative data.
group mix was far less than intended. Projects with strictly no or modest care need were rather exceptional and showed to be absent among the larger projects. In three cases the actual group mix deviated from the data in the KCWZ-database. Projects mixed with higher and no care need were extremely exceptional and only one of them was willing to cooperate. So only the sample of projects mixed with care reached full saturation, see the dark grey fields in Table 3.

<table>
<thead>
<tr>
<th>Physical scale in relation to group mix</th>
<th>Extra Small &lt; 80</th>
<th>Medium 81 - 130</th>
<th>Extra Large &gt; 131</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Wemeldinge</td>
<td>Jean Sibelius</td>
<td>Eindhoven</td>
<td>De Schermerij, Leersum</td>
</tr>
<tr>
<td>De Wemel</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>De Berken</td>
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<td></td>
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<tr>
<td>Meulhove</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domus Bona V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noorderoord</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huize St. Franciscus, Veenenda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mixed with higher care need</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Sfinx, Zeewolde</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eilandstaete, Arnhem</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>St. Annahof, Uden</td>
<td></td>
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<tr>
<td>De Berken</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Meulebeek</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Domus Bona V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noorderoord</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huize St. Franciscus, Veenenda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mixed with higher and no care need</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malburgstaete, Arnhem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4. Resulting strategic selection, studied projects classified to physical scale and group mix</td>
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</tr>
</tbody>
</table>

With respect to the projects mixed with care, the interrelationships between physical scale, location, group mix and social quality of housing could be well analysed. The other projects were analyzed as well, illustrating the exceptional kinds of group mix.

Scale experience and location

The data showed some clear patterns in the experience of scale. Small scale projects were higher appreciated in villages, large scale projects in cities. Inhabitants as well as initiators often mentioned the more assured experience of feeling safe in small scale projects, related to more informal contact and social cohesion in villages, see Narrative 1. In contrast, in cities large scale was higher appreciated because of a more assured mix of tenants bringing more liveliness and a larger variety of people and facilities.

Interaction and reclusion

As was already mentioned before, we saw far more extensively mixed projects than we assumed in advance. Groups with higher care need were present in 20 out of 24 projects, presenting 10-50% of the inhabitants. People with dementia and physical limitations were most present, people with mental limitations only rarely, people with psychiatric problems not at all. Regarding group mix a distinction should be made between accommodating different people or groups and actual interaction between people or groups. Concerning the concept of informal help and social interaction in Assisted Living Facilities various results were found. Group mix in itself does not automatically lead to social interaction and does evidently not prevent reclusion. Common activities, when connected to the needs of the diverse inhabitants, could reduce reclusion. However, a mix of groups can be confronting; when vital elderly are daily confronted with very frail elderly with disabilities and a high need for care they might get frightened about their likely future, see Narrative 2.

Narrative 2. Frightening future

Relational aggression

In most projects the different groups live next to but apart from each other. In one project one might even speak of ‘a little war’ between the groups with modest and higher care need. Relational aggression on personal or group scale was widely spread and had a strong negative influence. Elderly keep away from activities to avoid encountering certain persons or groups.

Limited informal care

In several projects we saw vital elderly giving support to other groups, which encourages social interaction. The inhabitants in the projects were by majority over 75, with a higher care demand, leaving only very limited opportunities to mutual informal care.

DISCUSSION

One of the limitations of this research concerns the selection of respondents. Most inhabitants were
selected by the care cooperation or housing association. In spite of the inclusion criteria this may have led to a certain bias by selecting easy approachable, possibly positive persons or members of residents committees. Another limitation is the staggering of interviews throughout almost a year. The influence of the seasons probably leads to different social behavior and different activities and as such different levels of satisfaction. Nevertheless some new and interesting insights came to the fore regarding the impact of physical scale and group mix on social quality of housing.

Revaluation of scale
The impact of physical scale on social quality of housing showed to have a different effect in connection to the location. The difference in appreciation of physical scale between villages and cities is not surprising but much stronger and pronounced than expected. Small scale satisfaction is well known and one of the drivers in present policy. However, we saw that specific large scale satisfaction in the cities was widely present. Thus, a choice for a larger scale has not just to be a result of management indicators. This postulates that the contemporary unilateral appeal for small scale facilities has to be revalued in connection to location characteristics.

The threat of mixing with high care need
Assisted Living Facilities were initially meant to accommodate vital elderly with a modest need for care. This tight definition was already criticized by Singelenberg6. The data of the population of Dutch ALFS showed that projects without tenants with a higher need for care are quite rare and almost absent in large scale projects. The newer generation of Assisted Living Facilities is characterised by a mix of vital elderly and elderly with a high(er) need for care, in particular people with dementia or somatic limitations. The expected mix with people not needing care at all, in order to prevent an atmosphere of an elderly people's home, is only seen in few pilots. There seems to be no small or medium scale project mixed with higher and no care needing tenants yet. The mix of low and (very) high level of care needing people brings opportunities as well as threats. With the aspiration of creating integrated groups within a project, in some projects a mix of people with physical limitations, mental limitations and dementia is being accommodated. However, the aim of stimulating informal care and social interaction depends heavily of the right balance between less and more dependent inhabitants. In projects were too many people are dependant from care and professional support, or an unbalanced mix due to a growing number of dependent people over the years, people are unable to contribute to the necessary informal care. Besides, the more care demanding group has a confronting impact to the vital elderly. This might lead to resistance to move to the project because of the severe 'care mark'.

The ongoing aggravation of a disproportional percentage of high care needing people may undermine the original concept of Assisted Living Facilities and requires reconsideration. There is a risk of losing the particular value of an ALF as a welcome solution between aging at home and aging in a hospital-like institution.

References
Speech-based interaction in an AAL-context

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Purpose The number of older persons in industrialized countries is steadily increasing. Seniors living alone are more numerous, and we must find solutions that will allow them to continue to stay at home comfortably and safely. Smart housings can be one of these solutions. One of the biggest challenges in ambient assisted living (AAL) is to develop smart homes that anticipate and respond to the needs of the inhabitants. Given the diverse profiles of the older adult population, it will therefore be essential to facilitate interaction with the smart home through systems that respond naturally to voice commands rather than using tactile interfaces. Method The first step in our study was to evaluate how well ambient assistive speech technology is received by the target population. We report on a user evaluation assessing acceptance and fear of this new technology. The experiment aimed at testing three important aspects of speech interaction: voice command, communication with the outside world, home automation system interrupting a person’s activity. Participants were 7 older persons (71-88 years old), 7 relatives and 3 professional carers; the experiments were conducted in a smart home with a voice command using a Wizard-of-Oz technique. The second step in our study was related to the adaptation of speech recognition technologies to the older adult population. Judging by the literature this has not been extensively studied. In fact, it is known that industrialized speech recognition system models are not adapted to seniors but to other categories of the population. In order to do this we recorded a specific speech corpus (voice-age) with 7 older adults (70 to 89 years old) reading sentences (a total of 4 hours of speech). A second corpus (ERES38) of free talking (18 hours of speech) was recorded by 23 speakers (68-98 years old). These corpora were analyzed in a semi-automatic manner to reveal the aged-voice characteristics. Results & Discussion Regarding the technical aspect, it appears that some phonemes are more affected by age than others. Thus, a specific adaptation of the acoustic models for ASR is required. Regarding the acceptance aspect, voice interfaces appear to have a great potential to ease daily living for older adults and frail persons and would be better accepted than other, more intrusive, solutions. By considering still healthy and independent older persons in the user evaluation, one interesting finding was overall acceptance provided the system is not conducive to a lazy lifestyle by taking control of everything. This particular concern must be addressed in the development of smart homes that support daily living by stressing the ability to control the daily routine rather than altering it. This study shows the great interest of voice interfaces to develop efficient solution to enable the growing number of older persons to continue to live in their own homes as long as possible.

Keywords: voice interface, speech recognition, ageing voice, AAL, smart home

INTRODUCTION

The demographic change and ageing in the developed countries imply challenges in the way the population will be cared for in the near future. A popular solution is to develop ICT to make it possible for older person to stay at home. Home support of older adults is related to several constraints: first, the increasing number of older persons who often wish to live independently as long as possible in their own homes; secondly, the cost challenge to society to support people loosing independence and; thirdly, the shortage of places in specialized institutions. Given these demographic trends and using new technologies, Ambient Assisted Living (AAL) research programs intend to develop services and innovative products that improve the quality of life of older people, maintain their independence and quality of life in a normal living environment whereas seniors are more affected by physical or cognitive diseases. Solutions must be developed to compensate the possible physical or mental decline to keep older persons with a good degree of autonomy. The aim is also to provide assistance if necessary through surveillance to detect distress situations. However, in the most general case, these persons are often confused by complex interfaces and technological solutions must be adapted to the needs and the specific capacities of this population. Therefore, as voice is the most natural way of communication, interfaces using a system of Automatic Speech Recognition (ASR) may be more accessible. The aim of this paper is to expose the possible uses of audio and speech analysis in the AAL context before presenting two studies involving older persons. The first study aims at evaluating how ambient assistive speech technology is received by the targeted population. We report a user evaluation assessing the acceptance and the fear of this new technology.
The second study is related to the adaptation of speech recognition technologies to the older population which has not been extensively studied in the literature, even if it is known that system development for other categories of population is not adapted to the senior. This article will terminate by a brief discussion about the results and by a presentation of the perspectives.

**Audio use in an Ambient Assisted Living context**

**Smart Home and AAL**

One of the biggest challenges in Ambient Assisted Living (AAL) is to develop smart homes that anticipate and respond to the needs of their inhabitants, this is especially important when they have disabilities. Smart homes are habitations equipped with a home automation system including a set of sensors, automated devices and centralized software which control the increasing amount of household appliances. Given the diverse profile of the elderly population, it is thus essential to facilitate interaction with the smart home through systems that respond naturally to voice commands rather than using tactile interfaces which require physical and visual interaction. Therefore, although speech interaction is rarely considered, it seems more adapted to people who have difficulties in moving or seeing. Chan et al. reviewed the projects with a medical perspective and identified the necessary conditions to satisfy, namely: - user needs, acceptability and satisfaction; - viability and efficacy of sensors and software; - standard compliance for information and communication systems; - legacy and ethical constraints; - cost reduction and socio-economical impact. Moreover, several studies were conducted to identify the needs of older people towards a system that can help them in their everyday life.

The proposed systems consider providing assistance in three main areas: - health (tracking the status of the person and the evolution of his loss of autonomy by using physiological sensors, motion sensors, video cameras, home intrusion, etc.); - security (preventing and detecting situations of distress or risks through fall detectors, smoke detectors, etc.); - and assistance for home automation systems (compensation of disabilities through better access to domestic appliances). It should be noted that a fourth priority must be added, it is the communication with relatives and with external persons which is essential for the person isolated at home.

**Audio sensing technology in Smart Home**

Audio analysis can be divided into speech recognition and sound identification. In this context, speech recognition is useful for voice command and dialogue while sound identification gives information about the activity of the person (e.g., closing the door or using the vacuum). Many challenges have to be overcome before these technologies could be usable and deployable in assisted living applications. Sounds are produced by very varied audio sources and then sound identification is less advanced than speech recognition which benefits from continuous progress since the use of probabilistic models (Hidden Markov Model-HMM) for phoneme modeling. Therefore, this section focuses on speech recognition application in smart homes.

**Extraction of speech in a noisy environment**

In real conditions, audio processing is affected by: background noise (TV, devices, traffic...), the room acoustic (reverberation on windows) and the position of the speaker with respect to the microphones set in the room. The most significant problem is related to speech signal mixed with unwanted noises such as music or vacuum. Sophisticated signal processing techniques should be considered to solve this problem (i.e. echo cancellation, blind source separation...).

**Voice interface for compensation and comfort**

Voice interface is a natural way of providing the ability of driving verbally the home automation system. It's a natural way to enable a physically disabled person (e.g., person in a wheelchair, blinds...) to keep control of their environment.

**Detection of distress situations**

Identifying specific sounds (glass breaking or falls) would be of great interest for such situation detection. On the other hand, voice interfaces make it possible to call for help when the person is in a distress situation but remains conscious. Moreover, gerontologists and physicians pointed out the importance of emotion in the voice. Automatic emotion level recognition would be highly helpful to detect an important problem to solve and then assistance is requested.

**Evaluation of the ability to communicate**

One of the most tragic symptoms of Alzheimer's disease is the progressive loss of vocabulary and communication skills. The changes can be very slow and difficult to detect by caregivers, and an automatic monitoring could allow the detection of important stages of this evolution.

**Speech recognition adapted to the speaker**

Several experiments established that automatic speech recognition performances are degraded for atypical population like children or aged persons. As AAL concern a lot older persons, this point will be the matter of a following section.
Privacy and acceptability

Due to the increasing number of sophisticated electronic devices, the question of privacy becomes crucial and speech recognition must respect privacy. Therefore, the Automatic Speech Recognizer (ASR) must be adapted to the application and should not be able to recognize private conversation sentences.

Regarding the acceptability point of view, a system will be more accepted if it is regularly used in the daily life such as with a home automation system, than if it is used in rare circumstances (e.g., fall). Acceptability is crucial because it conditions the use of the system by the person. Therefore the next section is devoted to this aspect.

Acceptability of Vocal Orders

Older persons are the most likely persons to develop cognitive and physical decline but that does not imply they are all not self-governing. Thus, the design of new daily living support technologies must take into account studies which showed that the reduction of sense of control in the elderly population may have a significant adverse effect on their health. Moreover, given the implication of the relatives in supporting their seniors, caregivers must also be included in the design. To find out what the needs of this target population are, we conducted a user evaluation assessing the acceptance and the fear of the audio technology. In the experiment we assessed the acceptability of such technology. This is the key factor for integrating new technologies in homes, particularly when the users are older persons or low ICT educated persons. In the following we present the experiment we set up to test users’ acceptance and a summary of the results.

Experimental set-up

The experience we undertook aimed at testing three important aspects of speech interaction in a smart home: voice orders, communication with the outside world, home automation system interrupting a person’s activity. It consisted in Wizard of Oz phases and interview phases in the smart home. The WOZ interaction consisted mainly in the control of the environment. For instance, if the participant said “close the blind”, the blind were closed remotely.

The participants consisted of 18 persons from the Grenoble area. Among them, 8 were in the senior group, 7 in the relatives group (composed of mature children, grandchildren or friends). The mean age of the elderly group was 79.0 (SD=6.0), and 5 out of 8 were women. These persons were single and perfectly autonomous. In order to acquire another view about the interest and acceptability of the project system, 3 professional caregivers were also recruited to participate in the experiment (2 nurses and one professional elderly assistant).

The co-discovery approach (see Figure 1) was chosen to reassure the senior about the experimental context (new environment, experimenter, etc.) thanks to the presence of their relative. Moreover, it eased the projection of both participants into the new system because they could exchange points of view. Of course, the relationship between the two people can also influence the experiment that is why some short periods were planned during which the participants were interrogated separately.

To assess the acceptability of the system which has no standard definition, most of the experiments were conducted to find out whether the potential users would appreciate the new functionalities brought by the system (e.g., “Do you appreciate making the system operate using your voice? Why?”). Moreover, in order to guide the development of the system, aspects of usefulness, usability, interactiveness, proactiveness, intrusiveness, social interaction, and security were investigated.

The first phase of the experiment was about the voice command aspect of the project. Both the senior and her relative were present in the room. The senior was asked to control blinds, lights and the coffee machine using her voice without any recommendation about how to do it. This consisted in talking “to the home”. The second phase consisted in using technology for communication with the outside such as video conferencing. The senior was left alone in the smart home watching a TV program, when the program interrupted itself to let the face of the relative appear on the screen so that they can start a conversation. The third phase focused on system interruption. The couple and the interviewer were discussing in the smart home when the system interrupted them via a pre-recorded voice played through the speakers, calling for a door to be closed.
or the cooker to be turned off. After this, questions related to whether being interrupted by the system was acceptable or not. Also, the problem of security in general and how such system could enhance security was discussed with the couple.

Results of the study
From the results of the study, it appears that seniors and their relatives preferred mostly the voice command, the system interventions about safety issues and the video-conferencing. It is interesting to note that, in our study, the “key-word” form for commands is highly accepted (rather than the sentence based command). This highly simplifies the integration of such technology in smart home given that small vocabulary systems are generally performing better in real world applications than large vocabulary ones.

As in other related studies\(^3\), all participants found a strong interest in the voice interaction system. It is strongly preferred over a tactile system (or touchscreen) which would necessitate being physically available at the place the command is to be found or would imply to constantly know where the remote controller is. This is in line with other studies concerning personal emergency response systems which showed that push-button based control is not adapted to this population\(^2\). Although the system was well accepted, it turned out that some functionality provoked strong objections among the participants. The main fear of the elderly and relatives is the system failure. Another main concern about the system is the fact that too much assistance would increase the dependence of the person by pushing her toward inactivity. Regarding the caregivers, they expressed the concern that such system would tend to gradually replace some of their visits and end up in making the seniors even more isolated. Most of these fears can be addressed by a good design of the system. However, fear about a decrease in autonomy due to a system that can do everything is a subtle one. A system designed for active people in order to improve comfort, security and save time may not be adapted to healthy but aged persons\(^2\).

While the proposed system can bring more comfort and autonomy to daily life by providing an easy interaction with the home automation elements, the majority of the participants insisted on the security aspects. For instance, the voice interface would be of great use in case of falls. The elderly and their relatives have particularly appreciated that the system spares the elderly actions that can be dangerous and warns them of dangerous situations. This trend is confirmed in almost all user evaluations involving elderly\(^2\). Thus, smart homes for the elderly would be much more accepted if they contain features that can reassure them regarding security more than any other features whatever their initial condition and origin in developed countries are.

Overall, the participants mainly stressed the interest of voice command and how this could improve security, autonomy and, to a smaller extend, could fight loneliness. However, they were very careful about privacy and clearly showed that they were very cautious of not accepting systems that would push them into a dependent situation. They want to keep control. Although only a small sample of seniors and relatives in healthy condition was recruited, this qualitative study confirmed the interest of voice-based technology for smart home and uncovered some pitfalls to avoid in its design. In the next section we describe a preliminary study to adapt standard speech recognition to the ageing voice.

AGEING VOICE
Speech of the older persons is characterized by tremor of the voice, an imprecise production of consonants, and a slower articulation\(^11\). From an anatomical point of view, studies have shown age-related degeneration with atrophy of the vocal cords, calcification of the laryngeal cartilages, and changes in the muscles of the larynx\(^12,13\). Given that most acoustic models of ASR systems are trained from non-aged voice samples, they are not adequate to deal with more aged population and then classical ASR systems exhibit poor performances\(^14,15,16\).

To improve the acoustic-phonetic decoding module in ASR systems and to adapt it to the voice of seniors, we studied the phonemes that were poorly recognized in an aged voice. To do so, we collected corpora, used ASR alignment and analyzed the most difficult phonemes. Then, acoustic model adaptation was done in order to evaluate the ASR. The main steps of the study are summed up in Figure 1.

![Fig.1. Main steps of the Ageing Voice study](image)

Speech corpora
Given the absence of oral corpus adapted to the assistance at home, we recorded two new corpora specific to home automation and distress detection: the Anodin-Détresse (AD or Colloquial-Distress) corpus\(^17\) and Voice-Age (VA) corpus\(^18\). AD is a corpus made of short sentences read by 21 speakers. Each of the 37 older speakers of VA read the 126 sentences of AD and long sentences extracted from newspapers or magazines.
Given the results of our first studies\textsuperscript{18}, we recorded a new corpus named ERES38 in order to improve the acoustic models for older persons by favoring the problematic phonemes such as plosives and fricatives. The ERES38 corpus is a collection of interviews useful to collect informal and spontaneous speech recorded in specific establishments, such as nursing homes. A reading was also performed during this interview. Plosives and fricatives were introduced in the text in order to be in context /a/, /i/ and /u/. The interviews were conducted with people more or less autonomous, cognitively intact, sometimes with serious mobility problems, but without other severe disabilities. The recordings began to be transcribed, and all readings were transcribed and checked. This corpus is used for acoustic model training.

Table 1. Main characteristics of the 3 speech corpora

<table>
<thead>
<tr>
<th>Corpus</th>
<th>Gender (M/F)</th>
<th>Age (min-max)</th>
<th>Duration (min)</th>
<th>Sentence number</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>10/11</td>
<td>20-65</td>
<td>38</td>
<td>2 646</td>
</tr>
<tr>
<td>VA</td>
<td>11/26</td>
<td>62-94</td>
<td>5h19min</td>
<td>9 052</td>
</tr>
<tr>
<td>ERES38</td>
<td>8/16</td>
<td>68-98</td>
<td>17h44min</td>
<td>7 600</td>
</tr>
</tbody>
</table>

Influence of ageing voice on Automatic Speech Recognition

To compare the influence of the Aged Speech (VA) and the Non-Aged Speech (AD) groups we use the Sphinx3 engine as ASR\textsuperscript{20}. Acoustic models were trained using the BREF120 corpus\textsuperscript{21}. The language model was trained with the transcript of AD in order to match the context of home automation voice commands. The result is a very small trigram language model with a vocabulary of about 170 words focused on error analysis of the acoustic-phonetic decoding step. A more detailed description of this system is available\textsuperscript{18}.

The decoding with sphinx3 generates an orthographic transcription of the audio signal of speech. We obtained a Word Error Rate (WER) of 7.33% for the Non-Aged Speech group (21 speakers) and a WER of 27.56% for the decoding of the Aged Speech group (36 speakers). Thus we observed a significant performance degradation of ASR for elderly speech, with an absolute difference of 20.23%.

A more precise analyze is given by the forced alignment scores by phoneme. Forced alignment scores are likelihood scores belonging to the phoneme normally delivered for the considered signal portion. This score can be interpreted as a proximity to the “standard” pronunciation modeled by the generic acoustic model. The difference of acoustic score for Aged versus Non-Aged is shown in Table 2.

Table 2. Difference of acoustic score in forced alignment for Aged Speech vs. Non-Aged Speech

<table>
<thead>
<tr>
<th>Phonetic group</th>
<th>Score difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal vowels</td>
<td>-117.00%</td>
</tr>
<tr>
<td>Unvoiced fricative consonants</td>
<td>-110.56%</td>
</tr>
<tr>
<td>Unvoiced plosive consonants</td>
<td>-105.72%</td>
</tr>
<tr>
<td>Voiced fricative consonants</td>
<td>-87.86%</td>
</tr>
<tr>
<td>Voiced plosive consonants</td>
<td>-83.29%</td>
</tr>
<tr>
<td>Medium vowels</td>
<td>-63.74%</td>
</tr>
<tr>
<td>Open vowels</td>
<td>-53.21%</td>
</tr>
<tr>
<td>Closed vowels</td>
<td>-45.52%</td>
</tr>
<tr>
<td>Nasal and liquid consonants</td>
<td>-42.65%</td>
</tr>
</tbody>
</table>

Consonants are generally most affected and the absence of voicing is the main factor of degradation followed by the modality of implementation (fricative vs. plosive). Therefore, it is possible that unvoiced consonants for older persons are closer to voiced consonants. These findings are in line with other results\textsuperscript{16} apart for the nasal and liquid consonants and the nasal vowels where their results are poorer.

Acoustic adaptation

The adjustment method of Maximum Likelihood Linear Regression (MLLR) was used to adapt the generic acoustic model trained with BREF120 to the voice of seniors. The adaptation was made globally with all sentences of the ERES38 corpus. The new acoustic model is the MLLR adapted model. The WER was then obtained for the 36 speakers (VA) using the generic model (WER\textsubscript{1}) and using the MLLR adapted model (WER\textsubscript{2}).

Results of the study

The speakers are grouped together using k-means clustering method based on observations given by WER\textsubscript{1} and WER\textsubscript{2}. The main characteristics of the 3 groups, number, gender and age, are reported in Table 2.

As shown in Table 3, using the MLLR Adapted Acoustic Model reduces the WER significantly up to 11.95%. Compared to the 27.56% WER without adaptation, the absolute difference is -15.61% (relative difference of -56.65%). From an applicative point of view, this shows that we can use a database of elderly speech to make MLLR adaptation with speakers which are different from the test base. This demonstrates that the voices of ageing people have common characteristics. Nevertheless, a little part of senior people (G03 group) can be characterized with poorer results of speech recognition. This group is not composed of the oldest people.
Table 3. Comparison of WER with the generic acoustic model (WER1) and the MLLR adapted model (WER2) for the 36 Aged Speech group

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender M/F</th>
<th>Age min-max</th>
<th>WER1 (%)</th>
<th>WER2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G01</td>
<td>4/13</td>
<td>70-92</td>
<td>13.58</td>
<td>5.54</td>
</tr>
<tr>
<td>G02</td>
<td>3/12</td>
<td>63-94</td>
<td>33.32</td>
<td>14.41</td>
</tr>
<tr>
<td>G03</td>
<td>4/0</td>
<td>62-84</td>
<td>65.38</td>
<td>29.97</td>
</tr>
<tr>
<td>All</td>
<td>11/25</td>
<td>62-94</td>
<td>27.56</td>
<td>11.95</td>
</tr>
</tbody>
</table>

CONCLUSION AND PERSPECTIVES

In this paper we present two studies aiming at investigating the feasibility of speech-based interactive systems. In the first study, the acceptability of a voice interface as part of the smart home was investigated. Voice interfaces appear to be better accepted by the seniors than more intrusive solutions such as video cameras. Otherwise, the “key-word” form for commands is highly accepted rather than the sentence based command. An interesting finding that came up is their overall acceptance provided the system does not drive them to a lazy lifestyle by taking control of everything. Smart homes could give seniors more ability to control their daily living.

The second study is related to the adaptation of speech recognition technologies to the senior population. Therefore, we recorded two specific speech corpora (Voice-Age and ERES38) which were analyzed in a semi automatic manner to reveal the aged-voice characteristics. Some phonemes are more affected by age than others, nasal vowels and consonants. Moreover, the absence of voicing is the main factor of degradation. Our current work is to complete this corpus in order to obtain more generic senior models. The CIRDO system will take advantage of these models to integrate new services for autonomy increase and make easier the support for relatives and caregivers.

Acknowledgments

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References


Aging-in-Place: A Challenge towards Sustainable Planning in the Dutch Housing Market

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Purpose Aging-in-place is an economically sound alternative for the current Dutch policy and legislation for housing senior citizen. Preliminaries for establishing aging-in-place are a good urban infrastructure for daily provisions, a service-framework for care-giving at home, and the availability of good housing for all, including disabled or frail citizens. This paper focuses on the availability of home-features that enhance independent living for senior citizen with disabilities. Establishing appropriate housing for all senior citizen depends on the availability of existing homes that either already have suitable provisions, or that are easy to retrofit. Adding newly built homes that support aging-in-place is the most direct way to improve the housing stock. However, western, increasingly grey, societies have stable, or even shrinking populations. Therefore, the creation of quality housing stock tends towards converting and renovating existing housing stock. Success of the retrofitting depends on the technical features of the existing homes. This paper aims to conduct a quick scan of the technical quality of the existing housing stock and the suitability of these homes to be converted into homes needed to support aging-in-place.

Method The amount of necessary homes for the age-cohorts for 2020 and 20304 and the composition of the Dutch housing stock by age and by home type5 were estimated through desktop re-search. Literature review produced preferences in the Dutch population towards affordable homes for seniors6. A valuation method7 that links the affordability to establish aging-in-place with technical features of the home by 4 performance indicators for affordable healthy housing quality was used. Each performance was linked to a parameter in technical features of home types. Five mainstream home types were reviewed for this set of parameters. Results & Discussion Most growth of households in period 2008-2030 is positioned in the cohort of senior citizen: from 1.6 to 2.7 million. Most existing homes are not provided with appropriate technical features to establish aging-in-place. Locating housing for seniors in existing neighborhoods would require large renovation programs which should include the home lay-out. Solidarity between generations is likely to become a problem in housing.

Keywords: Ageing-in-Place, healthy housing; performance, independent, urban planning

INTRODUCTION
Between 1945 and 1980 Dutch housing policy focused on encouraging senior citizens to leave their family home and move to retirement housing. Although this was contrary to the general housing policies in Europe the Dutch were attempting to meet the housing needs of the post-war baby boom families in the Netherlands. In 1970, up to 30 percent of senior citizens were living in elderly homes in the Netherlands. In 1970, up to 30 percent of senior citizens were living in elderly homes in the Netherlands. Until 1980 housing legislation was merely intending to tackle a shortage in two-genera-
tion family-houses rather than that is was providing appropriate housing for elderly. After 1985, the birth rates stabilized towards the common values in Eu-


Aging-in-Place
The English saying “My home is my castle (till death)” reflects for many senior citizens their ambition concerning their housing. In 2007 the European Commission started for this reason an initiative program Ambient Assistive Living2 that intends to promote a more active role in society for its European citizens. Preliminary requirements for establishing aging-in-place consist in a good urban infrastructure to facilitate obtaining daily provisions, a service-framework supporting care-giving at home and the availability of inclusive housing for all, including disabled and frail citizens. For older persons an extended independent living in the local neighbourhood

358
is providing much benefits. The nearness of neighbours, friends and family that are potentially providing informal help; the nearness of provisions for daily needs; and the embedding in social structures that is easing a continued social participation for the aging person. The restricted availability of dwellings that are suitable for housing even when disabilities appear remains a limiting factor.

**A changing housing-market**
A possible mismatch between changed housing needs of an aging inhabitant is not merely a simple problem for the involved aging person. It also impacts on the housing market. The gray grown birth gulf in the population will be confronted at large scale with their changing housing demands. While the number of suitable dwellings that meet this housing demands falls short, many persons will not obtain appropriate housing that addresses their declined health status. Thus their quality-of-life is threatened by an urban-planning that has failed to anticipate the foreseen needs of a graying society. The challenge is to plan sufficient dwellings that meet the requirements for Aging-in–Place.

**Sustainable Dwelling Design**
A grey growing society exists by the fact that a large part of its inhabitants are obtaining a higher age. This higher age is not predicting for the individual person whether he will suffer chronic impairments or that he will enjoy a vital health status. So far, the gain in years-to-life is hardly accompanied with a gain in healthy-years-to-life. A fine understanding of the causes for a declining health-status of its inhabitants is not that important for a housing-planner. The planner’s scope is the Life Cycle of a construction “dwelling”, which has to function for more than 40 years. From the point of view of sustainable production and use of dwellings, a continuous use of the dwelling without major adjustments for changing housing-needs is highly important. An extended independent-living in the same house is preferable, since it produces less waste of building materials by both refurbishing and renewing the home. The maximum level of grey-growing in the population is expected within the planned exploitation-period of a dwelling, designed to last at least 30 years.

**Changing housing needs**
In 2002 a housing corporation in Eindhoven conducted a large research on the housing-needs of all its renters, aged over 50. A majority of the renters opted for Aging-in-Place in a dwelling with garden, with three or four rooms on ground level and with a rather high level of comfort. Outcomes of other research showed the same results. In an earlier study older inhabitants of a Dutch retirement home were interviewed about their motives for choosing to give up their independent living. Four types of motives were dominant: chronically failing health, lacking social contacts, and poor quality of the existing dwelling and precaution for future burden. Since 1992 poor health-status has remained the only valid argument for admission into a retirement-home. This study indicated that the lack of suitable housing conditions strongly influences the choice for extended independent living.

**From senior inhabitant towards the “the bricks”**
This paper focuses on the availability of appropriate dwelling features supportive for aging-in-place. The ambient shell of building structures provides healthy- and comfortable living-conditions for its inhabitants. In figure 1 is given a scheme in which the housing-demands for the “indoor” living environment are connected with the technical features of the ambient building construction. In this scheme are connected the domains related to the quality of indoor-environment with the provision of appropriate building-components by means of building performances. The indoor-environment and its interaction with the human inhabitant is, to a high extent, linked with generic rules in the domain Building Physics. The dwelling-shell however has a giant variety of shapes and is constructed in a large range of different components. Given a restriction to the warmer humid climate zones the building-codes of West European countries such as The Netherlands and Great Britain provide specifications for maintaining an appropriate indoor-climate suitable for an average person most of the year. The generic building-codes however do not take the physics of aging-persons as a standard for its requirements. Thus a dwelling type, that meets the standards in the building-code, does not automatically address the requirements of the older segment of the population.
Planning versus free market
Why should we plan, let the housing market itself solve this problem of changing housing-demands? A graying society has to face its higher need for housing that meets the requirements for Aging-in-place. This depends on the availability of dwellings that either already contain suitable provisions or are easy to refurbish at low investments. When the housing-market is populated by appropriate dwellings, older inhabitants may easily move home to a dwelling that better suits their changed housing needs, and the housing market has worked. However, when large parts of a population “suddenly” have changing housing-needs, conversion of the quality-level of the housing-stock works too slowly.

Sustainable planning for a gray growing society
Adding new dwellings that support aging-in-place is the most direct way to improve quality in the housing stock. However, aging societies in the Western Hemisphere are facing stabilising- or even shrinking populations, and as a result the number of households will stabilize also. Thus the opportunities for realising additional dwellings will decline in the coming decades. In urban planning the production of new dwellings will change its focus from enlargement of cities towards large-scale renewal of old-fashioned dwellings and reconstruction of housing-complexes that lack sufficient technical quality. Reconstruction in the existing neighborhoods is gaining favor as a result in this conversion towards aging-in-place. The planning of appropriate housing for seniors must first estimate the number of dwellings in the existing housing-stock that meet the requirements for aging-in-place. The fortunate aspect of this planning is that the foreseen composition of the demand-side, the adult population, is easy to estimate. The problem lies in estimating the supply-side: what part of the existing housing-stock is already meeting the requirements for aging-in-place?

Is it possible to generalize dwelling-quality?
Quantifying this part focuses on specific features of dwellings that are present in a variety of typologies. However, in most statistics on national level the subdivision of dwelling-types is restricted. For the low cost-sector in social-housing the appropriate maximum of quality is more characteristic of the minimal quality standard allowed by the building code. The Building-Code rigidly applies many minimal technical standards and the design of low-cost dwellings was enhanced to produce standard-solutions for lay-outs in a limited range of preferred dwelling types. In the post World-War-II housing of the Netherlands more than 80 percent of dwellings fell into the low cost-sector. The development of standards in the Building Code is traceable in successive dwelling types with specific technical features. The local situation in the Netherlands showed a range of successive typical dwelling types that resulted from a successive revisions of the building-code.

Conversion in an existing housing market
The presence of more or less standardised dwelling types opens an opportunity to go into more detail concerning the technical suitability of the housing stock in meeting the changed housing-demands in a grey growing society; in this case the features that ensure aging-in-place. Which part and what features of the existing housing stock is opportune for conversion? What can be learned from data mining, of rather standardized dwelling-types in the Netherlands a country which has had a rigid building-code for decades, like?

From the point of view of public housing a relevant question is: To what extend is the existing house stock suitable for establishing ageing-in-place, whether directly or after minor (within months, not years) adjustments to the dwelling-construction? In the same line of building planning, what part the dwelling-stock is not meeting minimal standards for appropriate living in the future? Including the opportunity to realise thermal-insulated dwellings that afford inhabitants to more easily withstand the foreseen rising energy-costs for heating.

Answers to these questions in universal-housing first rely on a set of well-defined building-standards, secondly on a clear sub-division of dwelling-types and thirdly, on locations with homogenous climate conditions.

This paper presents a quick scan of the technical quality of the existing housing-stock which would allow conversions to support aging-in-place, a country with highly standardized dwelling typology, the Netherlands.

MATERIAL AND METHODS
Criteria are defined for suitable dwelling that are easy to refurbish., Desktop research has yielded estimates of the numbers of necessary dwellings for age-cohorts in 2020 and 2030.

Estimating volumes in dwelling types
Desk top research has yielded estimates of the actual house stock, subdivided for year of realisation and dwelling type. National statistical comparison however is limited to a very rough subdivision: ground-bound dwellings versus apartments, rental home versus bought home. For this study the proportions of the dwelling-categories Detached, Semi-detached, Row House and End-of-Row house found in surveys of sold houses are estimated equal with the proportions in the dwelling stock. For the Dutch national situation, a large part of hired dwellings is in
the budget sector and owned by housing corporations. Which nearly is a preliminary for renovation.

Criteria for Aging-in-Place
An existing Valuation Method\textsuperscript{10} that links performance-indicators for healthy-housing to the affordability for independent living in the dwelling was used. In this method nine performance-criteria were given that determined the affordability\textsuperscript{10}. Four criteria that were linked with the architectural- or urban shape, and five criteria linked with technical features, including thermal-insulation. A comprehensive assessment was made using these 9 criteria on the items related to the typology of dwellings and traceability in statistics on housing.

Performance indicators
Based on the development in the Dutch Building Code and Construction Standards for 4 technical features (1908\textsuperscript{11}, 1964, TGB 1968\textsuperscript{12}, 1976, 1977\textsuperscript{13}, 1992\textsuperscript{14}, 1995, 2002\textsuperscript{15} and 2012) the origin of the Dutch Housing production was separated in 5 periods of origin of the dwelling. Four performance indicators were each linked with a parameter in the technical features of dwelling types.

Five main-stream dwelling types in the Dutch context were reviewed for this set of parameters.

Typology of dwelling types
Existing typology of dwellings was used and was extended with the item "guarded-settlement" in order to achieve connection with the international variety in housing types on the feature Social Security.

Likely renewal towards Aging-in-Place
Analysis of the functional ability of dwellings to meet the requirements of aging-in-place was executed with Affordance\textsuperscript{16} Typology. An affordance is a mirror-shape of a function. I.e. a dwelling may be affording aging-in-place by its design, though it was not designed to do so. For the used performance indicators some combinations of negative result will however score positive at the aspect: suitability after renewal. The most negative result, older dwelling-type is not suitable for aging-in-place because of the very high construction costs which argues for reconstruction, if located in an existing neighborhood.

RESULTS
Three levels of suitability for establishing aging-in-place concern:
I, Direct usability for aging-in-place;
II, Usable after minor renewal (less than 3 months);
III, Unusable, optionally part of reconstruction.

Increase in housing for seniors
The Dutch ministry for Housing(2010)\textsuperscript{17} had estimated a growth in the number of households for senior citizens from 1,577 million in 2008 towards 2,648 million in 2030. The complete Dutch housing-stock will grow with nearly 1 million households towards 8,231 million in 2030. The number of rental homes in the budget-sector however will decline. The complete growth in households is located in 1,111 extra owned dwellings. Table 1. Shows the future developments in households. Approximately half of the future houses will be rental in the budget sector, an increasing half of contingent with a garden, the other half in apartments. This is in line with studies Housing needs of senior citizens in Eindhoven (2002)\textsuperscript{4} and Parkstad (2008)\textsuperscript{5} and the brief for senior dwellings Sir 55+ VAC\textsuperscript{18}. The housing demands in these studies tended towards a dwelling with 2 to 3 bedrooms. Demands for the dwelling itself and its outside room (garden, balcony) emphasized comfort and ease in housekeeping. The decline of 451,000 hired dwellings in the cohort 30-65 years provides an opportunity for new dwellings in the neighbourhoods.

<table>
<thead>
<tr>
<th>Mid-scenario</th>
<th>X Thousands households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2008</td>
</tr>
<tr>
<td>Nursing Home (beds)</td>
<td>300</td>
</tr>
<tr>
<td>Households, total</td>
<td>7,242</td>
</tr>
<tr>
<td>--Hired dwellings total</td>
<td>2,917</td>
</tr>
<tr>
<td>In it 30-64 years</td>
<td>1,656</td>
</tr>
<tr>
<td>--Owned dwellings</td>
<td>3,914</td>
</tr>
<tr>
<td>Senior households</td>
<td>1,577</td>
</tr>
<tr>
<td>Hired by seniors</td>
<td>871</td>
</tr>
<tr>
<td>60 % highest income</td>
<td>255</td>
</tr>
<tr>
<td>40% lowest income</td>
<td>616</td>
</tr>
<tr>
<td>--Owned by seniors</td>
<td>706</td>
</tr>
<tr>
<td>60% highest income</td>
<td>421</td>
</tr>
<tr>
<td>40% lowest income</td>
<td>285</td>
</tr>
</tbody>
</table>

Senior population households 2,998

Table 1. Development in households from 2008 to 2030 specified for age cohort, for owned -- and rented dwellings Source data Ministry BIZA Netherlands 2010

Dwelling Typologies
Dwelling types in National Dutch Statistics are firstly divided in independent living and temporary living in a nursing house/ hospital. Independent living secondly in ground level dwellings and apartments, in hired status versus ownership. Fourthly for ground-level dwellings in Detached, Semi-detached, Rowmid and Row-End Dwelling type. Patio-bungalows are part of the detached type. Fifthly, for location, a guarded intermediate terrain between the public street and the private entrance door of the dwelling, versus a ill-defined intermediate zone, such as in gallery-apartment buildings, or an absence of an intermediate terrain. In the Netherlands apartments in nursing house or nursing hospital are of the guarded...
Assessing criteria for aging-in-place
A comprehensive assessment was made for 9 criteria for aging-in-place on the items: relation with architectural typology of dwellings and traceability in statistics on housing.

1. Ergonomics, elevator for apartments
Criterion Ergonomics is strongly related with the access from the public domain into the building, the position of the dwelling in a building i.e. ground level or elevated level, and into the successive rooms in a dwelling, i.e. zero-level dwelling versus multi-storey dwelling with a stairs.

1. Ergonomics, zero level dwelling
This ergonomic criterion is related to the opportunity to realise at zero level a living room with kitchen, a master bedroom and a bathroom. In doing so it indicates a rule of thumb: width of a dwelling is larger than half of the sum of following rooms:
- Width of sleeping zone, critical at length of bed 2,1 m plus passage for wheel-chair, 0,9 m in total 3,0 m.
- Width of living zone, most minimal measure 3,3 m
- Width of kitchen zone, critical at sink depth 0,6 m
- Plus turning circle wheelchair 1,5 m. Total 2,1 m.
- Entrance zone dwelling, minimal at circle wheelchair
- Or entrance path 1,2 plus width of toilet 1,0 m
- Building construction 0,3 m plus intersection wall
Theoretical minimum width is for a dwelling the sum 3,3m+2,1 + 0,4= 5,8 m. Rule of thumb Universal width of aging-in-place dwelling at least 6,0 m

3. Social Security
Criterion Social Security is strongly linked with an intermediate guarded zone between the public space and the private dwelling. Several types of settlement are linked with this difference of dwelling entrance. However in the given example of The Netherlands this distinction is not made in statistics. This lack of security is optionally compensable by ambient intelligence, domotic-installations and services for alarm and follow-up

5. Stable Thermal Indoor Climate
Criterion Stable Thermal Indoor Climate is not related to the variation in typology of dwellings. However is strongly related to the year of origin of the building, since building standards for thermal insulation have progressed during the decades. Thus this criterion is retraceable in statistics of housing. Thermal insulation concerns a preliminary condition since it determines the affordability of living-costs.

2.4. 6.7.8.9. Four Other technical features
Criteria Sunny outside room, Visibility, Emissions from building materials, Acoustics, Biologic Agents, Air-refreshment were not directly related to the architectural design.

A. City Provisions
The general criteria City Provisions are not traceable in statistics. Since existing house-blocks in general are situated at locations with short distance to existing city-provisions for daily needs, this leads to a generic recommendation: situate aging-in-place favorably in existing older neighborhoods.

B. Functional Design
The criterion Functional Design itself is not traceable in housing statistics. Since the ergonomics has its effects on building standards and building codes, this criterion delivers decisive parameters for zero-level dwellings. As a result the Dutch house stock may be divided into the minimum standards for dwellings before 1977 and after that date. Three effects have to be mentioned within the Dutch context after 1977: first-level floors in concrete, standardized small openings for the stairs and a strong standardization in dwelling width. As a result of rigid urban planning the width of standard two-storey row-houses and semi-detached houses was fixed on 5,4 m since that time.

C. Building Joints
The criterion Building Joints, though not related to a specific architectural type, addresses the feature Stability of Construction and is strongly related to progress in building standards. For the Dutch legislation, the TGB 1968 is divisive. Multi-storey buildings designed before 1968 must be mistrusted for stability. Correction of this failure is only possible at high costs.

Resulting 4 used performance Indicators
Resulting were 4 performance indicators:
1.- Thermal-insulation; year of origin 1980 or later
2- Stability of construction Apartment-Building with a year of origin after 1970
3- Width of dwelling 6.0 m or more
4- Elevator for Apartment-buildings, for mid-high apartments year of origin 1980 or later.

**Periods of origin of dwellings**

For the Dutch situation is used a sub-division in:

- Period before 1945 with dwellings that are not insulated, that mostly are national heritage.
- Period from 1945 until 1978, dwellings in large ranges, no thermal-insulation, for mid-high apartment-complexes (up to 4 floor-levels) no elevator
- Period 1945 until 1970 apartments are lacking a stable construction.
- Period after 1980, dwellings insulated, apartments in a stable construction and all with elevators.

**Affording Aging-in –Place: remarks**

Next to the above 4 performance indicators are positioned in table 2 remarks 1 to 9:

1. Dwellings of an origin after 1980 contain thermal insulation that affords low energy-costs for living.
2. Apartments before 1970 lacked both stability of construction and thermal-insulation. Reconstruction will bring appropriate housing in the neighbourhoods.
3. Mid-High apartment buildings after 1980 that lack an elevator afford a low-cost renovation at this point.
4. Budget-dwellings of the type row-house before 1970 had a standard width of 6 m, however were not thermal- insulated nor acoustical-insulated. Besides specimen of national heritage, an intensive large scale reconstruction of hired new dwellings following the existing property lots is a sound alternative.
5. In case of ownership of these row-houses refurbishment of the individual dwellings is a more likely plan.
6. Detached houses of all periods in general are ownership. Individual renewal of the layout of the dwelling for aging-in-place technically is a sound option, also when the dwelling is not insulated yet.
7. Semi-detached dwellings with individual ownership also afford the same successful refurbishment.
8. Dwellings of origin before 1945 mostly are under national heritage. Not suitable for a large scale Renewal, thus these dwellings are not considered.
9. All low cost dwellings with an origin after 1980 have a width of 5.4 m, and mostly a concrete storey floor.

**Direct usability of dwelling types?**

Systems for domotics\(^{22}\) have to be installed in all dwellings. Only a small part of the existing dwelling stock is directly usable for aging-in-place, category I. Some dwelling-types afford Aging-In-Place after renewal, category II.

---

**Millions of dwellings**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before 1945, all types</th>
<th>Before 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Comfort: Thermal Insulation</td>
<td>8</td>
<td>0.72</td>
</tr>
<tr>
<td>2. Stability of construction</td>
<td>3</td>
<td>0.36</td>
</tr>
<tr>
<td>3. Width of dwelling &gt; 6.0 m</td>
<td>4</td>
<td>0.74</td>
</tr>
<tr>
<td>4. Elevator</td>
<td>5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Remarks 1 to 7**

- Apartments, 1945-1970
- Apartments 1970-1980
- Semi-detached, Row
- Hired, 1945-1980
- Ground level, Owner
- Apartments, hired
- Apartments owner
- Row-houses owner
- Row-houses rental
- Semi-detached owner
- Detached, owner

**Result**

- I Directly suitable Aging-in-Place 0.81
- II Suitable after Refurbishment 2.43
- III Potentially demolished 1.76
- Fitting for urban reconstruction

Table 2. Dwellings in the existing housing stock that are fitting for Aging-in-Place in the Netherlands, with 4 performance parameter and 5 dwelling types over 4 periods of origin of dwelling. Sources diverse\(^{23,24,25}\)

The third category of dwelling-types, however, will not reach a quality-level that suits affordable housing without incurring extreme building-costs. Category III is a potential subject for urban reconstruction programmes within old neighborhoods. Table 2 gives an overview of the dwelling-types, their score for 4 performance indicators and the output in the above categories I,II,III.

**DISCUSSION**

Apart from the results that have their relevance for the Netherlands some general remarks are to be made about the used quick scan method, that is using an analysis of housing stock by dwelling-type.

**Variety in building codes**

The use of dwelling-typology for achieving quick scan data relies on a strong intersection of dwelling-types resulting from both a building-code that is setting the minimum standard and economic rules, that determine whether the minimum level is the maximum result. In countries with less rigid building-codes, the variety of dwelling types will be larger. Besides, the used ergonomic parameters reflect to a certain extend differences in prosperity of countries. As already stated in the text, the used parameters are also only valid in humid-, moderate-climate zones. From the point of view of building-physics,
the general starting points will easily result in parameters that cope with the regional-climate conditions.

**Differences between countries and regions**

For every country the proportion of dwelling types in ground-level and apartments, in hired or owned, in row-house or (semi)detached will differ. In countries like USA with a high proportion of Detached dwellings the conversion of a substantial part of the housing stock into a dwelling-quality that supports aging-in-place will be rather simple. In a country with a high proportion of two-storey row-houses or old high-rise apartment-buildings without elevator, more problems will occur. In the European discussion rural regions with shrinking population will benefit from better planning of the required types and volume of dwellings and in arguing for more new dwellings that support Aging-in-Place.

On a local level, quick scanning with dwelling-typology opens a new way for planning the conversion of dwelling-types within the existing neighborhoods. Local research will provide more details concerning features that determine the suitability.

**Focus on outcomes example Netherlands**

Table 3 presents the Dutch housing-stock combining the outcomes in demands from table 1 and in available appropriate dwellings from table 2. The Dutch situation achieves a balance between the required building effort in coming decades and the potential use of existing dwelling-types in the dwelling stock. Criteria for needed aging-in-place are informed by the co-morbidity rate. Reconstruction of not fitting dwellings in criterion III seems at least necessary. Criterion I implies that all senior citizens will achieve a dwelling, that affords Aging-in-Place. A large part of the dwellings for seniors is to be located in the existing neighborhoods. A quick view learns that the complete volume of new dwellings is equal to the volume of additional dwellings for senior citizens. This opens a conflict of interest between generations. However the seniors have to be housed in existing neighborhoods, while the additional dwellings are located at new town extensions plans for second generation families.

From the point of view of sustainability an additional remark concerns the similarity in housing-needs of young citizens and the senior citizens. While the guarded stand-alone senior-citizens ghetto is no option, a strong focus on the changed housing-needs may stimulate flexibility in use of dwellings between the generations. The housing-comfort of Aging-in-place for all inhabitants. Inter-generational dwellings provide a benefit for a sustainable long-term planning of housing. Even beyond the maximum of a gray grown society in 2030.

Top down national urban-planning is no longer an issue in the Netherlands. A bottom-up awareness of shortages in dwellings that suit senior citizens has to find its way, most probably in the local planning.

| In thousand households, Demand Available |
|----------------|----------------|
| Data from table 1 and table 2 | In 2030 | In 2008 |
| Senior households total | 3.000 | |
| 20 % 3 or more disabilities Nursing hospital/ home | 600 | 350 |
| Directly suitable dwellings | | 810 |
| 70 % 2 or 3 disabilities Available dwellings at criterion II | 1.500 | 2.430 |
| 100 % seniors in neighborhood Directly suitable dwellings, I Dwellings, Minor adjustments II Recontruction new dwelling III TOTAL potential | 2.648 | 810 2.430 0- 1.760 3.250 to 5.000 |

Table 3. Balance future required dwellings for seniors and Possibilities to use existing dwelling-types

**References**

6. VROM (Dutch Ministry of Housing), “Senioren op de woningmarkt”, (seniors at the housing market), 2010.
13 VNG Dutch Unity of Communities “Voorschriften en Wenken” (requirements for social housing), 1977.
14 VNG First national Building Code Netherlands, 1908.
17 BiZa Ministry Internal Affairs “Woningmarktverken-ning 2010” (Survey Housing Market), 2010.
Purpose
This paper presents a new method to retrieve concrete crack properties based on image processing techniques. Method Detection and quantification of cracks in concrete bridges pose various challenges. Cracks have fewer pixels compared to their background. For effective visualization, the objects need to be captured from near field. But it is not always possible to capture the complete cracked surface in a single frame while taking the image from near field. Hence image stitching is required before pre-processing of images for further analysis. Usually retrieved images have low contrast due to environmental and equipment limitations which add another difficulty in image visualization. State-of-the-art image pre-processing as suggested in the literature may not be suitable for images captured in different environmental conditions. This paper discusses various techniques for image enhancement using point processing, histogram equalization and mask processing. Furthermore, a binary image is required to obtain a skeleton of an object. However, the pre-processing techniques cause discontinuity in crack alignment. Morphological techniques (e.g. dilation) are used in this work through successive iteration to ensure connectivity. Then the object skeleton which is unaffected by expanded boundaries is obtained by using skeleton algorithm to retrieve concrete crack properties such as length, bounding rectangle, and major and minor principal axes lengths. Results & Discussion The preliminary results obtained using this methodology is capable of retrieving length, orientation and bounding box of the identified cracks. This method is aimed at assisting in obtaining automated prediction of condition state (CS) rating of cracks in bridges. It can be also used as a tool for post-earthquake damage evaluation purposes.

Keywords: concrete bridge crack, image stitching, image skeleton, crack properties

INTRODUCTION
Bridge inspection reports are the fundamental input parameters for any Bridge Management System (BMS) to access safety and functionality of bridges. Before carrying out any detailed inspection for repair and maintenance, the preliminary inspections of bridges such as counting the number of cracks, maximum length and width of cracks, existence of scaling and spalling defects, and presence of corrosion are important to be recorded in inspection reports. Often, Bridge inspection and maintenance have been manually conducted by making a trip to the site. From the structural point of view, the evaluation of crack properties plays a vital role in bridge inspection and decision making process. However, manual retrieval of crack properties presents many difficulties. For example, cracks usually have very small numbers of pixels as compared to their backgrounds. Due to this, it is difficult to locate these cracks from a far field position. In many cases, the inspection of bridge elements from near field may not be possible due to site inaccessibility. Subsequently, crack visualization could be another problem in accessing crack properties due to insufficient lighting conditions or dirt present on the concrete surfaces. To obviate such problems image processing techniques could be used retrieving image properties automatically. The concept of automation based on image processing is becoming popular for bridge inspection process. Image processing techniques have been successfully utilized to detect cracks on concrete surfaces.

In this paper, we collect sample images of cracked surface of concrete bridge decks to apply the proposed methods and highlight their limitations to address the above issues. Close range photographs are necessary to enhance cracks properties, but many photographs are required to cover the entire cracked region. This paper discusses image stitching algorithm as well as various image enhancement algorithms to capture cracked image properties which will assist the automation of bridge inspection based on image processing techniques.

BACKGROUND
Cracks in concrete structures are very common that we see in our daily life which do not only degrade the appearance of structural members but also reduce carrying capacity of whole structures. As a result, crack widths are limited on various concrete surfaces depending upon types of structures. As specified in Ontario Structure Inspection Manual (OSIM), crack width greater than 1.0 mm is considered as poor
condition state and crack width less than 0.3 mm is considered as good condition state. Tian et al., 1986 have also mentioned that crack width as one of the parameters for assessing deterioration of concrete surfaces. For the past several years, many machine vision approaches have been suggested to retrieve crack properties using image processing techniques. For example, Abdel-Qader et al. compared the effectiveness of crack detection techniques such as fast Haar transform (FHT), fast Fourier transform, Sobel, and Canny. It was found that FHT was more reliable than the other three techniques. In 2006, Abdel-Qader et al. proposed a Principal Component Analysis (PCA) for pattern recognition (cracked or not cracked) based on Euclidean distance measures as similarity measures. In addition, Cheng et al. proposed a crack detection method based on threshold operation using mean and standard deviation of gray-level image. But the threshold method does not ensure proper connectivity of the crack alignments. To solve this problem, percolation-based image processing method was suggested by Yamaguchi and Hashimoto to correctly detect cracks. But none of the above works discusses the crack stitching problem when crack images are taken from near field. Zhu et al. 2010 proposed an automated method to detect large-scale bridge column composed of multiple of close range images. They used SIFT detector (Lowe 2004) to locate an object and artificial neural networks for material recognition to detect column.

However, image quality is highly dependent upon complex environment and lighting conditions. Due to noise caused by irregular illumination, various shadings and moisture present on concrete surfaces, it is always difficult to distinguish cracks from their backgrounds. They separated crack pixels from their background by manipulation of gray-level correction showing bimodal histogram of crack image. For proper image visualization, Yamaguchi et al. addressed that dynamic range of camera and lighting conditions (uniform or non uniform) are important to have satisfactory results. But they do not discuss how these parameters can be controlled if the acquired image is dark or lighting condition is non-uniform. A method has been proposed here to enhance the global appearance of an image based on the spatial domain operation which can directly works on image pixels.

Automatic crack property feature extraction is application dependent. Practically, it is not feasible to develop a generic algorithm to extract any object properties form any images. There is always human intervention at some point in automation process and the acceptable level of human intervention shall be defined based on accuracy, efficiency, and repeatability. Yamaguchi et al. used a calibration line based on crack scale and brightness of the crack. Miyamoto et al. calculated crack width based on the difference of brightness in cracked and un-cracked areas. Additionally, they reported that no unique crack width is obtained even if the intensity is uniform because it is dependent on many factors such as un-uniformity of brightness, angle of view and orientation of cracks. Zhu et al. calculated crack properties based on skeleton segment information and distance field. They calculated average distance of skeleton points and double of the result represents the average crack width.

**METHODOLOGY**

In the 2011 Annual report of the office of the Auditor General of Ontario it is recommended that a risk-based approach be used for the ongoing monitoring of inspection. One of the important aspects of risk-based approach in bridge inspection is to determine and compare crack properties with the allowable limits specified for individual members. Figure 1 shows the proposed methodology to retrieve crack properties in bridges.

![Fig.1. Research Methodology](image)

**Image stitching**

Cracks have less numbers of pixels as compared to their background. In a single shot of a camera, human eye cannot visualize cracks in bridge elements and hence multiple shots with zooming of camera need to be taken in order to get sufficient information on cracks. These individual crack frames need to be combined first before doing any image operations. This research adopt the image stitching algorithm developed by Brown and Lowe, 2007, based on extracting image invariant features and matching them with new images. This method has several advantages over other available methods. This method does not require image initialization or a fixed image ordering. It is based on feature based registration which is invariant to rotation, zooming, and illumination change in the input images. After invariant feature extraction, the algorithm search for
matching of images based on overlapping areas. This method is suitable for crack stitching problems for the present work as demonstrated in Figure 2. Two images captured at different parts of a cracked region are shown in Figure 2 (a & b), and the stitched image is shown in Figure 2(c).

![Fig.2. Example of Image Stitching: a) and b) part images of a crack region, c) stitched image](image)

**Image pre-processing**

A commercially available SONY-DSC T5 digital camera of 5.1 mega pixels with optical zoom 3x has been used for data collection of bridge crack surface defects. In this work, each photographic frame includes either a natural or artificial target for scale calibration to get pixel values in millimeter. After image acquisition, pre-processing is required for image enhancement. Generally, there are two image enhancement methods that can be applied: spatial domain operation, and frequency domain operation. Spatial domain operation is divided into three parts based on the particular needs. They are point processing, histogram based techniques and mask processing. The proposed method adopts spatial domain operation (directly work on image pixels) as mask processing for crack detection operation and histogram based techniques for visualization enhancement. Both processes are described in details here.

**Histogram Equalization (HEQ):** This method enhances the global appearance of image which helps to visualize small cracks with human eyes. In most cases, fine cracks are invisible due to poor illumination, dirt on concrete surfaces or small dynamic range of cameras. HEQ makes use of a transfer function as defined in Equation 1,

\[
S'_h = T(r_h)
\]

(1)

Where, \(S'_h\) and \(r_h\) are the intensities of the processed and original images, respectively.

The mapping function given by Equation 2 is used to convert the normalized value of histogram to the dynamic range value.

\[
S' = \text{Int}\left(\frac{S - S_{\text{min}}}{1 - S_{\text{min}}} + [(L - 1) + 0.5]\right)
\]

(2)

where, \(S'\) is the mapped intensity value, \(S_{\text{min}}\) is the minimum intensity of the processed image, and \(L\) is the maximum intensity level.

![Fig.3. a) Original Image, b) Plot of Histogram](image)

**Fig.3. a) Original Image, b) Plot of Histogram**

The output of the above algorithm has been presented in Figure 3 and 4. Figure 3 shows the original image and the associated histogram, while Figure 4 shows the enhanced image and the resulting histogram. The enhanced image clearly provides a better visualization of cracks than the original image.

![Fig.4. a) Enhanced Image, b) Plot of Histogram](image)

**Fig.4. a) Enhanced Image, b) Plot of Histogram**

The Cumulative Distribution Function (CDF) shown in Figure 5. By designing a special type of transfer function, an image can be enhanced using the histogram specification algorithm. The Cumulative Distribution Function (CDF) that can also be used as a transfer function for image enhancement is shown in Figure 5. By designing a special type of transfer function, an image can be enhanced using the histogram specification algorithm.

**Mask processing for Crack Detection:**

Mask processing is used for image smoothing purpose. Although mask processing reduces noise, it
increases blurring. For this work, a mask size of [7x7] pixels has been used for image smoothing. Also, a non-linear filtering operation (median Filter Operation) which considers an output pixel value equal to the median value of above adopted mask size has been used. The purpose of this process is to obtain candidate cracks as illustrated in Figure 6. This method plots gray intensity level for a selected rectangular area and plots column-wise average intensity of gray value (Fig. 6 – top). Similar operation is performed on the smoothed image (Fig. 6 – middle). The candidate cracks are obtained by subtracting the smoothed image from the original image (Fig. 6 – bottom). The change in intensity profile indicates the presence of cracks.

Retrieval of Crack Properties:
Crack Definition: A crack is defined by the end points, and it may be simple or split (i.e., branched). In Figure 7, cracks are shown by 4-corner stars and splitting points are shown by 5-corner stars. The length of a crack is either distance between end points or splitting points or between an end point and a splitting point. Crack widths are calculated in mm using reference of some natural targets in picture frames.

Threshold Operation: The threshold operation is performed on the pre-processed images using the following three methods: (a) maximum entropy; (b) Otsu; and mean of the intensity in the given image. As shown in Figure 8, the maximum entropy (entropy is a measure of the uncertainty of an event taking place) provides a better contrast to detect a crack. This method maximizes inter-class entropy instead of maximizing inter-class variance.

Erode and Dilate: Dilation replaces each pixel in an image with the maximum intensity value in the 3x3 neighborhoods. This operation is performed iteratively until cracks are fully connected. But, before doing this operation, the noise present in an image needs to be eliminated by eroding operation. Figure 9 compares threshold image with eroded image. During eroding operation, many of the pixels in the image are lost which may affect the continuity of the pixel map of a crack. The continuity is re-built by the dilation operation as shown in Figure 10.
is superimposed image the skeleton to extract width and length of crack properties\textsuperscript{21}. Distance map and skeleton of a given crack are shown in Figures 11 and 12, respectively.

![Fig.11. Dilatation and Distance Map](image1)

![Fig.12. Skeleton and Superimposed image](image2)

![Fig.13. Crack length divided in segments](image3)

<table>
<thead>
<tr>
<th>ID</th>
<th>Length in mm</th>
<th>Width in mm</th>
<th>Average Width in mm</th>
</tr>
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<tbody>
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</tr>
<tr>
<td>D4</td>
<td>141.46</td>
<td>1.79</td>
<td>2.16</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Implementation and Results**

ImageJ\textsuperscript{22} is commercially available image analysis software, which has been used here for image processing of the pictures of cracks in bridge elements. A typical crack-skeleton as shown Figure 13 has been subdivided into 5 segments to extract its length and width based on crack definition. The width is calculated at the ends and the center of each segment. The results are recorded in Table 1. The crack profile such as width vs. length of the crack has been plotted as shown in Figure 14. From such figures constructed for a crack at different time intervals can provide useful information about the growth (in length and width) of the crack.

![Fig.14. Crack Profile along Length of Crack](image4)

**Discussion**

A number of methods available for retrieval of the properties of cracks on concrete surfaces has been utilized to develop a systematic procedure for processing of images of damaged areas of concrete surfaces in bridge elements. The proposed scheme is suitable for automatic retrieval of crack properties. But in practical terms, there are a numbers of challenges that need to be considered before applying these algorithms. For example, in old concrete surfaces, cracks edges are often widened because of scaling of plaster or cement mortar. Also, many flacks are often seen along the length of cracks. Due to these defects, predicted crack width would be more than actual crack width.

Inspection report is an integral part in any Bridge Management System (BMS). But manual inspection is time consuming and costly. Tracking concrete surface properties using image processing techniques are fast and less costly. So, this information can be used as primary level of bridge inspection which can provide basis for detailed investigation if any abnormalities exist. The proposed method overcomes some of the limitation pointed out by Zhu et al.\textsuperscript{21}. For example, their test results showed that irrespective of how accurate detection techniques are, there are some cracks visible to human eyes, but not visible in images. To some extent, this limitation has been overcome by the proposed method. Moreover, many of the past crack detection methods fail to detect fine cracks. Fine cracks are lost during threshold operation. This problem can also be solved by image stitching techniques as demonstrated in this work. However, a number of challenges exist for inspection of concrete surfaces for effective BMS except those pointed out earlier. Condition rating of concrete slabs is required for ranking of bridges in database to select proper candidate for further maintenance and rehabilitation. Additionally, the existing crack pattern may not be of much important
for inspection engineers, but how the crack pattern is changing with time will be valuable information for safety of structures.

**CONCLUSION**

Traditionally visual inspection, which is the primary method in use, is slow and expensive. In the present work, image processing techniques are used to extract concrete crack properties. While there are a number of methods available for the crack detection and representation, they are suitable in some controlled situations or in particular images. The present research focuses on visualization of images and detection of thin cracks which are often lost during pre-processing. Cracks have less number of pixels as compared to their background. Histogram threshold is not suitable in such cases because in many cases, crack objects are not visible in histogram plot. For effective visualization of objects, the images need to be captured from a near field. But it is not always possible to capture complete cracked surface in single frame while taking image from a near field. Hence image-stitching is required before pre-processing of images for further analysis. Usually retrieved images have low contract due to environmental and equipment limitation which adds another level of difficulty in image visualization. Existing techniques for image pre-processing may not be suitable in different environmental conditions. A combination of various techniques for image enhancement such as, point processing, histogram equalization and mask processing is necessary to pre-process the images appropriately. Furthermore, a binary image thinning is required to obtain a skeleton of an object. However, pre-processing techniques cause discontinuity in crack alignment. A morphological technique such as, dilation is used to ensure connectivity through successive iteration. From an object skeleton obtained using the skeleton algorithm, the crack properties such as length and width is determined. The proposed method overcomes limitations such as detection of thin cracks which may not persist after pre-processing of an image. The extracted width can be used for condition rating of concrete members and the extracted crack pattern is important for comparing the change in crack patterns over time.

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371
Dynamic planning of earthmoving projects using system dynamics

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Purpose The purpose of this paper is to present a dynamic planning model for earth moving operations through capturing the operations context level (scope change, skill level, etc.). Method Uncertainties, scope, and changes in project condition call for dynamic modeling of earthmoving operations. Static planning and scheduling methods such as CPM and PERT neglect – and are incapable of – considering project dynamics and causal-effect loops that exist between project variables. In an effort to address this challenge, system dynamic modeling and simulation is utilized in this research to plan and simulate earth moving operations. The developed model consists of three modules: (i) a work flow module that focuses on work execution from excavating the material until dumping it as demonstrated in; (ii) a resource module that captures the resources’ interactions and estimates the required resources based on the variables governing the site condition and management requirement; and (iii) a cost module that estimates associated costs with project’s operations. Results & Discussion The model was tested using a real case from Marzouk and Moselhi. The model outputs demonstrate that including the project context variables and their cause-effect loops to the planning stage of this category of projects improves the planning process. The developed system dynamic model is expected to enhance project modelling; capturing the interactivity among its variables to provide more realistic modelling for its schedule and cost. It also can assist members of project teams to predict a variety of likely scenarios and develop suitable action plans.

Keywords: earthmoving planning, system dynamics, simulation

INTRODUCTION

Earthmoving operations are common in heavy construction projects. Considerable efforts have been made to develop efficient models and systems for estimating earthmoving operations’ productivity and fleet configurations that yield optimum outcome2,7,8,12,13. Earthmoving operations exist in a dynamic environment with high influence from the operation’s context on the performance. For instance, equipment breakdown, inclement weather, unexpected site conditions9, scope change, and schedule pressure are factors that may give rise to uncertainty. Traditional scheduling methods such as CPM and PERT do not directly take into account such uncertainties11.

Construction is inherently dynamic, involving multiple feedbacks14. Nevertheless, this dynamic nature has not been explicitly addressed by traditional planning methods such as CPM and PERT. Project failure can be attributed to poor representation of the inner and outer aspects of operations. Uncontrollable external forces are often cited but the real cause may be internal such as the results of the cause-effect relationships between the project variables. Good project management should take into account the adverse external influence as well as the internal structure of the project systems. It has long been recognized10 that inadequate modeling of factors at the strategic level of projects results in their failure to achieve targeted objectives.

System dynamics approach can be used as a solution to capture the impact of such strategic factors on earthmoving operations. In construction, the use of system dynamics approach that considers approximately the entire construction operations as system consists of variables that interact overtime. This approach of modeling is practiced informally in the form of mental models. The mental models are nothing but models developed by managers in their minds based on their accumulated experience to understand what are the causes and what are the expected effects. Usually such models are simple, developed for limited number of variables involved in cause-effect relationships. When the project gets larger with involvement of many variables, the human mind fails to comprehend and relate many variable interactions in a system. This difficulty prevails over by utilizing rules and regulations of system dynamics planning method as well as the computer computation.

The system dynamics approach of project management is based on a holistic view of the project management process that focuses mainly on the interactions of the system’s variables in a feedback process. It offers a rigorous tool for describing, explor-
ing, and analyzing of complex projects. Variety of aspects influences project performance including development process, resources, project's scope, and targets. These four aspects interact throughout the project cycle in a complex fashion to reach to the project goals. The traditional management methods describe the four mentioned aspects in a static fashion that account only for duration, cost, and resources. Bundling all the effective aspects of the project in single activity duration as the case in the network methods hinders better project planning and performance measurement. Furthermore, they tend to ignore project dynamics and cause-effect relationship that exists between the project's variables.

**PROPOSED METHODOLOGY**

The propose methodology utilizes system dynamics modeling technique to build special purpose model for earthmoving operations. The model accounts for the dynamic nature inherited in construction operations as well as for capturing the cause-effect relationships among the variables considered in the operations. The proposed model consists of three main modules. The first is work flow module that describes the work flow and its execution from the initial scope to completion. Cause-effect relationships arising from scope change, rework, and deviation of project from its planned duration and productivity are built. The second module is the resources module, which generates the required resources (e.g. excavators, loaders, labors, and trucks) based on the planned project duration, productivity, and scope of work. The third module is the cost module; designed to calculate direct and indirect costs of the operation being modeled. The cost module takes into account the dynamic nature of the operation and makes adjustments to generate as realistic cost as possible. The proposed system dynamics model is built in Vensim PLE® Version 5. Due to space limitation, this paper focuses only on the development of work flow module as explained in the following section.

**MODEL DESCRIPTION**

A system dynamics simulation model is a series of differential equations based on feedback relationships that represent interactions among its elements. The stocks, flows, and cause-effect relationships of the developed model are represented by equations designated with parentheses [e.g., (1)] and demonstrated in Appendix A. The work flow structure demonstrated in Figure 1 is adapted from Ford and Sterman. Similar structures are also developed to represent project dynamics and its cause-effect feedback loops.

The first step in building the system dynamics model of earthmoving operation is to identify the model boundary. The model boundary identifies the model's scope by classifying the model's variables into endogenous (value changes during simulation run), exogenous (value remains constant during simulation run) and excluded variables. Table 1 summarizes the built model boundary.

<table>
<thead>
<tr>
<th>Endogenous</th>
<th>Exogenous</th>
<th>Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality, actual productivity, actual duration, perceived productivity rate, schedule pressure, actual progress, forecasted productivity and required resources</td>
<td>Project deadline, scope change, equipment theoretical productivity, error rate.</td>
<td>Safety, fatigue, undiscovered error, secondary error cycle, resources constraints.</td>
</tr>
</tbody>
</table>

The developed system dynamics work flow structure is demonstrated in Figure 1. The stocks (represented by boxes) represent the work that either needs to be carried out or are already completed. The arrows represent the direction of work flow while the valves represent the rate at which work stocked is processed. The stock 'initial work to do' is the initial work scope; e.g. the material to be excavated and hauled to the dumping site (1). This stock is connected with the inflow 'added scope' (2) and the outflow 'reduction in scope' (3). The inflow accounts for the anticipated positive scope change during project execution phase while the outflow accounts for scope reductions. Such addition or reduction affects the project productivity. This effect is captured by using reference models that quantify the reduction rate of the productivity fleet due to scope change. The flow 'excavation' (4) represents the rate at which the excavators execute the work which is controlled by work scope and rate of excavation. Required rate of excavation (5) is determined by the planned excavation rate as well as available fleet keeping in mind the rate change is based on many factors such as equipment maintenance and schedule pressure. Excavated material is stocked in 'excavated material' sock (6). The loading rate (7) is determined by the stock 'excavated material' and available loading equipments.
Fig. 1. System dynamics model of earthmoving flow of work operations.
The stock ‘quality assurance backlog’ (8) is the point where the work is checked to meet set standards and specifications. The percentage of work that passes the quality check is ready to be hauled (9) while the work that does not pass the quality check is passed through a rework cycle (10, 11, and 12). It was assumed that the work will be reworked only one time to reach the required material quality; this means that the reworked quantities of work will pass quality standards. The reworked work after completion is admitted to material ready for hauling in stock ‘hauled material’ (13). The flow ‘work completion’ is the rate at which the hauled material is dumped at the construction site (14). Work released is the final actual productivity of the model and the actual productivity rate is calculated by dividing the quantity of ‘work release’ by the associated simulation time (15). This calculates the productivity rate at every time point during the execution phase. The described six stocks of the model are constrained by resources, change in scope, and schedule pressure.

**MODEL TESTING**

The model was tested using standards of system dynamics method. The inputs parameters of the earthmoving operation are shown in Table 2. These are the inputs for the system dynamic model.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Scope</td>
<td>100,000</td>
</tr>
<tr>
<td>Planned duration</td>
<td>150 hours</td>
</tr>
<tr>
<td>Scope change</td>
<td>10% of initial scope</td>
</tr>
<tr>
<td>Excavators productivity</td>
<td>180 ton/hr in first 20 hrs then increase to 120 tone/hr</td>
</tr>
<tr>
<td>Loader productivity</td>
<td>200 ton/hr in first 20 hrs then increase to 216 tone/hr</td>
</tr>
<tr>
<td>Labor productivity</td>
<td>190(+)STEP(5,8)+STEP(10,24)) ton/hr</td>
</tr>
<tr>
<td>Quality and efficiency level.</td>
<td>80%</td>
</tr>
</tbody>
</table>

The model ran for 160 hrs; setting the STEP TIME equal to 0.125 hr (i.e., the time interval where the model updates its variables’ states at the end of each interval). The model results show that the scope of work was completed in 155 hrs as shown in Figure 2. As it can be noticed from Figure 2, the total scope is the initial scope that was set at 100,000 ton and was subjected to scope change of +10% of the initial scope.
The project planned duration was set to be 150 hrs. After running the model, the scope of work was completed in 155 hours. The ratio of schedule pressure (time required to complete the work divided by available time) is calculated at every hour during running the simulation model as shown in Figure 7. The figure shows high schedule pressure ratio at the start of work (first 16 hrs). This is compatible with what is seen in construction execution where productivity increases gradually as the operations progress. The rest of the model shows steady schedule pressure ratio ranging from 0.05-0.3 schedule pressure and subsequently taking corrective actions in the form of increasing the resources to prevent schedule slippage.

CONCLUSION

This paper presented a dynamic planning model for earthmoving operations by utilizing system dynamics. The proposed model can capture the cause-effect relationships that exist among the variables impacting earthmoving operations. The developed model allows for capturing the neglected dynamics in tradition planning methods and overcoming their static nature. The proposed model can predict the required resources, productivity, schedule slippage, and time needed to recover. Furthermore, it accounts for scope change during execution of the project and for smoothening of assigned resources to perform the new increased or decreased scope. This model can be enhanced by adding the effect of other variables such as weather, overtime, skill level and equipment maintenance.

REFERENCES


APPENDIX A

MODEL’S EQUATIONS
1-Initial work to do= INTEG (added scope-Excavation-scope reductions, Initial scope).
Units: m3
2- Added scope= IF THEN ELSE (Time= 50, Initial scope*Added Scope rate, 0).
Units: m3/Hour
3-Scope reductions= IF THEN ELSE (Time=150, Initial scope*scope reduction rate, 0).
Units: m3/Hour
4-Excavated material= IN TEG (Excavation-Loading, 0) Units: m3/Hour
5-Excavation rate= Excavator productivity*“No. of excavators” Units: m3/Hour
6- Excavation= MIN (Excavation rate, Initial work rate) Units: m3/Hour
7-Loading=MIN (Loading process rate, Loading rate) Units: m3/Hour
8-Quality Assurance backlog= INTEG (Loading-Error discovery-Hauling, 0).
Units: m3
9-Hauling = MIN (QA rate-Error discovery, Hauling rate)
Units: m3/Hour
10-Error discovery=Error rate*QA rate.
Units: m3/Hour
11-Rework= INTEG (Error discovery-Rework rate, 0) Units: m3
12-Rework rate= MIN (RW resources rate, RW process rate).
Units: m3/Hour
13- Hauled material= INTEG (Hauling + Rework rate-work completion, 0).
Units: m3
14- Work completion= Hauled material/dumping time.
Units: m3/Hour
15-Work released= INTEG (work completion, 0) Units: m3
Challenges of Identifying Steel Sections for the Generation of As-Is BIMs from Laser Scan Data

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Purpose When a laser scan is performed and no prior information is available about the building, standard sections of components need to be identified from point cloud data in order to generate informative as-is building information models (BIMs). Currently, the standard steel sections used at a site are not automatically identified from the point cloud data. Various issues related to the laser scan data, challenge automation, such as occlusions, missing data points, angle of incidence, and imprecision of measurements on the data. Method The research described in this paper relates to the manual determination of steel beam sizes used in a steel worker training facility, which contained about 16 beams, 63 columns, and 12 scans collected over 4 days of construction. Results & Discussion We identified that occlusions and noise are the major challenges associated with recording accurate dimension measurements. The identification of correct steel sections based on such inaccurate measurements is even more challenging since the decision should be based on all defining (e.g., flange width, depth) dimensions.

Keywords: as-is BIM, as-built BIM, point cloud data, laser scanning, steel structures

INTRODUCTION

As-built or as-is Building Information Models are being generated for a variety of purposes, including retrofitting, architectural renovation, documenting site conditions, spatial program validation 1. Laser scanners are getting a lot of attention for collecting 3D data regarding the geometry of the building for BIM generation with the advantages of speed, coverage, and considerably long range 2. Identifying section dimensions from the laser scan data imposes challenges. It was reported that mixed pixels can cause sectional losses up to 5.6 cm on bridge column dimensions 3. Furthermore, occlusions, low point density, and surface reflections can further reduce the quality of the information obtained from the laser scan data 2.

Identification of steel sections is one of the most challenging cases of the object identification problem. In steel structure identification, sub-millimeter level accuracy is generally required. The structures can be complex and so the occlusion rates can be high. Steel components can have shiny surfaces leading to reduced data accuracy. The aim of this study is twofold. First, we would like to understand the range of errors that can occur due to the unique nature (e.g., small section sizes, accuracy requirements, occlusions, complexity) of steel structures and components. Second, we would like to understand the challenges of identifying steel sections from the laser scan data.

In order to investigate the severity of the problem, we performed a case study on an objective data set. By objective we mean that the data set shouldn’t be generated with special precautions to impact the results of this study. It should depict the generic problems one might face when performing a similar task on a different data set. The testbed used in this study is a training facility for steel erectors. The laser scan data was collected for automatic construction site progress and process monitoring in sequences. The BIM was generated by a professional company for potential uses such as evaluation of object recognition algorithms.

In this study, we manually recorded the all six dimensions of the I-Beams (i.e. section height, bottom and top flange widths, web thickness, and bottom and top flange thicknesses) composing the steel structure. Then, for each section, we identified the top 3 sections from the AISC Steel Sections 4 table that would fit to the dimensions identified. Assuming that no prior information is available regarding the structure, the identification stage was performed independent of the BIM. Identified sections were ordered by how well the identified sections describe the true sections. The identified sections are compared to the BIM for quantifying the identification accuracy. Potential challenges of identification of standard steel sections based on laser scan data were evaluated by observation.
IDENTIFICATION OF STEEL SECTIONS FROM LASER SCAN DATA

In order to understand potential challenges of steel section identification from the laser scan data and study the problem, we set up a testbed based on an objective data set. Using the laser scan data, we first manually identified the steel sections from the laser scan data. Then, we compared the identified steel sections with the reference BIM. Finally, by studying the patterns of bad estimates and the laser scan data, we identified the challenges of the identification problem specific to steel modeling.

The Testbed

The testbed used for this study is a training facility used for training ironworkers in erecting a steel structure. The purpose of the scanning was to monitor the process and the progress of the erection. The structure was laser scanned and the data was collected over a period of 4 days from 12 different locations.

The structure was scanned after every component was erected. Hence, the scan data captures the progress of the erection. The scans were performed when there is erection activity on site and workers are present. Scans were registered using fiducial targets.

The configuration of the steel structure during the erection composed of a permanent 4 story tower and the lower two stories that were erected during the training. About 36.5 million points were collected over the course of the training. In the figure it can be seen that there are also a partial basement floor (Level 0) and two beams on the top floor of the tower, which we called Level 5 throughout the paper.

A professional company generated the BIM of the structure. The BIM of the structure and the laser scan data constituted the testbed of this study.

Measurement method

Currently, such modeling tasks are carried out manually. Hence, we used a manual method for measuring the dimensions of the steel sections. However, several approaches can be adopted for manually recording the measurements. In order to identify the best suiting method to our testbed, we examined four different manual approaches on a small portion of the laser scan data.

The metrics we used for the evaluation of the manual measurement methods were overall accuracy of identification, easiness, and time. We define easiness as how comfortably the operator performs the measurement task with a given method. We asked the operator to compare the methods verbally to assess the easiness.

The measurement methods used for recording the section dimensions are as following:

1. **Point-to-point measurement**: This method manually selects two points for every dimension (e.g. top flange width) and records the distance between these points.

2. **Distance between edges**: In this method, the distances between the edge lines of a component are recorded. The edges are created by manually selecting the points along the edges and fitting lines to the points belonging to the edges.

3. **Distance between plane-plane intersection lines**: Similar to the second method, the distances between the edges are recorded. However, in this method, first planes are fitted to the surfaces of the components (i.e., flange surfaces and web surfaces). These planes are intersected to find an estimate of the location of the edges.

4. **Cross-section tracing**: In this method, cross-sections are cut through the point cloud. Projecting the points that are within a
small tolerance from the cutting planes and connecting the points generates cross-section traces. Dimensions are measured on these traces.

For each of the tested methods, 6 measurements were made along the components for every dimension of the components. For example, AISC steel section tables define I-beams using 6 dimensions (i.e., the depth of the section (D), the width of the top flange (W1), the width of the bottom flange (W2), the thickness of the top flange (t1), the thickness of the bottom flange (t2), the thickness of the web (t3)). Therefore, for an I-beam a total of 36 measurements should be made (6 measurements for each dimension times 6 dimensions).

After recording the measurements, we compared the measurements to the BIM dimensions. Based on the application of the four methods on a small subset of the scan data, we assessed that the first method (point-to-point measurement method) is equally accurate compared to the other three methods while being easier and faster to apply. Though, it should be noted that this assessment cannot be readily generalized without further investigation since the comparison is workflow specific. For our purposes, however, the aim is identifying a method that can produce accurate measurements on the point cloud. Therefore, we selected the first method for the rest of the study.

**Best Section Selection**

After all the measurements are recorded for all of the components, standard steel sections that correspond to those measurements are identified. Since the measurements were performed independent of the BIM and assuming no prior information, first, the shapes of the sections were identified. It was assessed that all of the components are W-shaped steel sections.

The standard section closest to the measurements was named the best fitting section (or the best estimate). It was observed that the average measurements were not always exactly equal to the dimensions of the standard steel sections from the AISC table. Additionally, the measurements had standard deviations of several millimeters. With such variation, it was not always possible to narrow down the selection to a single standard section. Therefore, we selected the top three standard sections that best fit the measurements.

Ideally, all six measured dimensions of the steel sections should be treated equally when comparing the measurements to the AISC section table. However, flange and web thicknesses were often at the order of the standard deviations recorded. The increments of thicknesses between different standard steel sections were almost always smaller than the standard deviation of the measurements recorded. For example, for a component with a measured flange thickness of 1.73 mm and standard deviation of 0.2 mm, the selection should be made between 33 sections. For the same component with the average section depth of 40 mm and standard deviation of the depth of 0.2 mm, there is only one W-shaped component in the AISC table. Therefore, preference was given to the depth of the section and the flange widths over thickness dimensions.

**RESULTS**

The reference BIM file was used to check the accuracy of the best fitting sections. The three best fitting sections were compared to the steel sections from the as-designed BIM file. The components where the best fitting section was matching with the correct section from the BIM were referred to as the accurate estimates. There were also cases where the 2nd and the 3rd best estimates were matching to the correct sections from the IFC file. The cases where none of the best sections were matching with the correct section from the BIM were classified as ‘No hit’.

For the columns, our best estimate was the correct section for only 18.75% of the cases. The second or the third best estimate was the correct section for 50% of the cases. For almost one third of the columns we were not able to determine the correct section.

For the beams, the results were slightly better. We were able to find the correct steel section for 39.68% of the beams. For 22.22% of the beams, we were not able to determine the correct section.

**CHALLENGES OF IDENTIFYING STEEL SECTIONS BASED ON THE SCAN DATA**

Based on the obtained results and close investiga-
tion of the scan data, we identified that there are several reasons as to why identification of correct steel sections is a difficult task. Namely, the challenges that can be attributed to this difficulty are associated with occlusions and noise in the laser scan data.

Occlusions
Obstruction of the laser beams by the components in the structure or by other objects (e.g. construction equipment, workers, etc.) causes occlusions in the laser scan data. From the BIM generation perspective occlusions prevents either the identification of the shape of the components or the correct identification of the dimensions of the components. The former is caused when a component is completely occluded. The latter is caused by the fact that due to occlusions, some of the dimensions of the components cannot be measured. A common example is that when a flanged beam is scanned only from one side the web thickness cannot be measured. Therefore in order to measure all dimensions, the components should be scanned from all sides.

In our testbed, for only one of the components the occlusions prevented any dimension measurement. However, partial occlusion rates (ratio of the number of partially occluded components to the total number of components) were high.

Partial occlusion rates for each floor are given in Table 2. Rates are calculated as the number of occluded components on a given floor divided by the total number of components on that floor. For example, 85.71% of beams on level 3 had partial self-occlusions. Unrelated objects partially occluded 42.86% of the components on the same floor (Table 2).

Table 2. Distribution of occlusions by level

<table>
<thead>
<tr>
<th>Total number of components</th>
<th>Self-occluded</th>
<th>Unrelated objects</th>
<th>Undefined edges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td>16</td>
<td>2 (12.5%)</td>
<td>1 (6.25%)</td>
</tr>
<tr>
<td>Level 0 Beams</td>
<td>17</td>
<td>1 (5.88%)</td>
<td>13(76.47%)</td>
</tr>
<tr>
<td>Level 1 Beams</td>
<td>15</td>
<td>2(13.33%)</td>
<td>5(33.33%)</td>
</tr>
<tr>
<td>Level 2 Beams</td>
<td>11</td>
<td>7(63.63%)</td>
<td>8 (72.72%)</td>
</tr>
<tr>
<td>Level 3 Beams</td>
<td>11</td>
<td>7(63.63%)</td>
<td>6 (54.54%)</td>
</tr>
<tr>
<td>Level 4 Beams</td>
<td>11</td>
<td>7(63.63%)</td>
<td>6 (54.54%)</td>
</tr>
<tr>
<td>Level 5 Beams</td>
<td>2</td>
<td>1 (50%)</td>
<td>2 (100%)</td>
</tr>
</tbody>
</table>

Missing data almost always resulted in wrong measurements. We identified a special case, however, where although the standard deviation of the measurements were low the measurements were not close to the actual dimension. In such cases, high precision (low standard deviation of measurements implies high precision) did not mean accuracy of identifying the best section accurately. This special case is caused by consistent occlusion throughout the component. The occluded parts of the section cannot be measured as expected. Additionally, since the occlusion is consistent through the member the spread of the recorded measurements are low although they are far from the actual values. For example, the standard deviation of the measurements of depth of section for Beam 108 was only 0.13mm (less standard deviation implies a precise measurement) and the average measured depth was 3.19mm. But the actual depth of section is 15.88 mm.

Noise
Noise in the data caused the spread of the measurement values to a wide range. Data noise was mostly caused by mixed pixels as the laser beams hit the edges of the components. This spread is measured by the standard deviation of the measurements. Standard deviations were often comparable or even larger than the difference between consecutive sections in the AISC steel sections database. This constitutes a challenge because it is no more possible to narrow down the search to a single component.

In the identification of the best estimate the best estimates were chosen to the sections within the interval of $[\mu - \sigma, \mu + \sigma]$ where '$\mu$' is the mean value of the measurements and 'sigma' is the standard deviation of the measurements recorded.

Table 3 shows example cases of the number of sections falling within one sigma range of the mean value of measurements. The sections are counted individually based on each dimension. For example, for
Column 1, basing the best fitting section on only the section depth gave 5 choices whereas basing the best fit guess only on the top flange thickness gave 115 choices.

Also, finding the best fitting sections for some sections was a challenge as none of the dimensions were helpful in finding best fits. For example, Beams 108 and 113 have absolutely no best fitting sections from any of the dimensions. The reason was that the mean measurement values did not coincide with any value in the table and within one 

$\bar{\mu}$ range there were no sections.

Beam 109 has 77 best fitting sections and beam 112 has 52 best fitting sections based on the top flange thickness. The solution sets were considered to be very large. In such cases, the standard sections with the closest values to the mean measured dimensions were chosen as the best fitting sections.

Additionally, the section estimates with respect to individual section dimensions, such as those in Error! Reference source not found., did not have intersecting sets of sections for some of the cases. Therefore, for those cases, using more dimensions did not help with the selection.

**SUMMARY AND CONCLUSIONS**

In this paper, we reported on our research on manual identification of the standard steel sections from the as-is point cloud data from laser scanners. For this, dimensions of the sections were measured on the point cloud data and these measurements were compared with the AISC database to find the best fitting sections. These best fitting sections were checked for accuracy using the as-designed BIM file.

The results of the identification showed that the best estimate was only accurate for 18.75% of the columns and 39.68% of the beams. For 31.25% of the columns and 22.22% of the beams, none of the estimates were the correct section.

We assessed the major challenges for recording measurements in point cloud data to be occlusions owing to the shape of the sections and unrelated objects like equipment, mixed pixels at the edges and noisy data. Particularly, large standard deviation of measurements compared to the section dimensions was the major reason behind the low identification rates. The results prove that modeling steel structures with the current equipment technology and processing workflows is a difficult and low accuracy task.

In this paper, we used a manual method for recording the section dimensions and selecting the sections. Additionally, no prior information was used to aid in the selection process.

This study aims at quantifying the accuracy of identification of steel sections from laser scan data. To the best knowledge of the authors’, such a quantitative evaluation does not yet exist. The testbed and the results of the manual identification could be used as a baseline for comparison and evaluation of object recognition algorithms on this dataset for future studies. The results of this study points to the low accuracy of laser scanners in imaging small details.

Identification process could be improved using statistical or machine learning methods. Instead of treating all the measurements equally, statistical methods could be used to filter out measurements with lower confidence.

Additionally, prior information about the structure can

<table>
<thead>
<tr>
<th>Section</th>
<th>Based on D</th>
<th>Based on W1</th>
<th>Based on W</th>
<th>Based on t1</th>
<th>Based on t2</th>
<th>Based on t3</th>
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<td>Beam 504</td>
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</tbody>
</table>
greatly simplify the process. The search space could be constrained from several angles using such information. For example, the search could be performed among the sections that are known to be used in the structure.

ACKNOWLEDGEMENTS
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References
Bid Decision Making with Prospect Game Theory

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Purpose This study proposes a new bidding decision model (Prospect Game Theory Model for Bidding Decision, BD-PGTM) for construction companies to set optimal bidding prices. Method This study has successfully integrated fuzzy preference relations (FPR) with fuzzy rating (FR), cumulative prospect theory (CPT) and game theory (GT). FPR was employed to forecast implementation probability for bidding strategies, and to simplify and overcome traditional reliance on evaluator experience in prediction. FR was introduced to forecast value functions and probability weight functions of competitor’s primary decision maker (PDM), and to solve the problems of inability to elicit competitor’s preference functions. CPT was included to calculate the prospect value of all companies’ PDM for all bidding strategy combinations. Lastly, GT was used to analyze PDM-determined bidding strategy. The optimal bidding prices derived from the proposed approach will be able to secure both the contract award and be as profitable as possible. Results & Discussion This study has verified the proposed BD-PGTM by using actual bidding projects from construction companies in Vietnam. It has also helped PDM to get exact optimal bidding prices.

Keywords: bidding decision making, cumulative prospect theory, game theory

INTRODUCTION
A significant amount of construction projects is apply a competitive bidding process, and award the lowest bidding price one which meet the stated specification. Bid price typically includes construction cost and profit, the latter can present as mark-up size multiplied by construction cost. The profit is the primary incentive of winning and executing contracts. The winning contractor must be able to set a mark-up size that secures the contract while sustaining profitable. So in the bidding decision process, after deciding to submit a bid, the bidders must decide what mark-up size to use on the submitted bid. Due to high uncertainty, intense competition, and difficulty in quantifying risks, the process of deciding mark-up size is very complex, which requires simultaneous assessment of a large number of highly interrelated variables to reach a decision. But for the limitations of rational and information process, the decision makers can not consider all relevant variables. In practice, contractors usually make bid decisions in a highly subjective manner that may actually lack a foundation in reason. And the decision is based on a mixture of “guts” feelings, experiences and guesswork. The typically emphasize factors like contractor experience, intuition, and personal preference, which are not conducive to approach standardization. In light of such, there is a practical need for a mark-up size decision-making model to fit the construction company’s practices. Early mark-up scale estimation models employed probability theory to predict the probability of winning a particular contract. Recently, expert system, case-based reasoning, neural network, analytical hierarchy process, and fuzzy set theory are adopted in bidding decision making. A BD-MCPM model was proposed, which combination FPR with CPT to help primary decision maker (PDM) determine which projects should be bid and the optimal mark-up size. This study combined game theory (GT), cumulative prospect theory (CPT), fuzzy preference relations (FPR), and fuzzy rating to create a new decision model named Prospect Game Theory Decision Model for Bidding Decision (BD-PGTM). This model can help the construction company’s PDM to determine the appropriate bidding price in a multi-competitor condition.

LITERATURE REVIEW
Fuzzy Preference Relationships
Many important decision models have been developed which focus mainly on: (1) multiplicative preference relations (MPR) and (2) FPR. In MPR, an expert assigns a value which reflects the degree of preference to each pair of alternatives. For a set of alternatives X is represented by matrix A=[a_{ij}]=X×X, \( a_{ij}=[1/9, 9] \) and \( a_{i1}=a_{1i}=1 \) for \( i,j \in \{1, \ldots, n\} \). When \( a_{i9} \) denotes that \( x_i \) is preferred absolutely to \( x_9 \), and \( a_{1i} =1 \) represents no difference in preference between \( x_1 \) and \( x_i \). A FPR on a set of alternatives X is represented by a matrix B. Matrix B are a fuzzy set on product set X×X that is characterized by membership function \( \mu_b : X \times X \rightarrow [0,1] \). Therefore, in \( B=[b_{ij}] \) and \( b_{ij}=\mu_b(x_j, x_i) \) for \( i,j \in \{1, \ldots, n\} \), where \( \mu_b \) is a member-
ship function, and $b_i$ is the preference ratio of the alternative $x_i$ over $x_j$. While $b_i=0.5$ denotes that $x_i$ and $x_j$ are indifferent, and $b_i=1$ represents that $x_i$ is preferred absolutely to $x_j$. Matrix $A$ can be transferred into matrix $B$ by using transform equation $b_i=(1+\log a_i)/2$. The relative weights $w_i$ for all alternative i can be obtained by using function $w_i = \sum b_i / \sum b_i$. Previous studies have given significant attention to fuzzy preference relations.

**Cumulative Prospect Theory**

Tversky and Kahneman proposed the CPT to describe individual preferences or subjective consciousness needed to choose among risky prospects.

Consider a prospect $X$ with outcomes $x_1 \leq x_2 \leq \ldots \leq x_n$ that is associated with probabilities $p_1, \ldots, p_n$. Cumulative prospect theory predicts that people will choose prospects based on the prospect value generated by:

$$V_{CPT}(X) = \sum_{i=1}^{n} \lambda \pi_i v(x_i) + \sum_{i=1}^{n} \pi_i v(x_i).$$

Where $v(x)$ is the utility function, $\lambda$ is a loss-aversion parameter, and $\pi$ represents decision weights calculated by “cumulative” probabilities $p_i$ associated with outcomes $x_i$. The function of $v(x)$ is not changed from the original prospect theory, show as below:

$$v(x) = \begin{cases} x^\alpha & \text{if } x < 0 \\ 0 & \text{if } x = 0 \\ -\beta(-x)^\alpha & \text{if } x > 0 \end{cases}$$

Decision weights employed in CPT are obtained by:

$$\pi_i = \sum_{j=1}^{i} w^+(p_j) - \sum_{j=1}^{i-1} w^-(p_j), 2 \leq i \leq k$$

and

$$\pi_i = \sum_{j=1}^{n} w^+(p_j) - \sum_{j=1}^{i-1} w^-(p_j), k+1 \leq i \leq n-1.$$ 

The boundary decision weights are $\pi_1 = w^+(p_1)$ and $\pi_n = w^-(p_n)$. The probability weighting function $w^+$ and $w^-$ are represented the condition of losses and gains individually. Such may be estimated experimentally by using the following formulae:

$$w^+(x) = x^\delta/(x^\delta + (1-x^\delta))^{1/\delta}$$

and

$$w^-(x) = x^\gamma/(x^\gamma + (1-x^\gamma))^{1/\gamma}.$$ 

CPT was successfully applied for medical decision making.

**Game theory**

GT has been widely used in the social sciences (most notably in economics) as well as in biology, engineering, political science, international relations, computer science, social psychology, philosophy and management. The theory attempts to explain behavior in strategic situations or games mathematically by recognizing that successful decision-making depends on the choices of others. A game consists of a set of players (i.e., decision makers), a set of strategies which are available to those players, and payoffs for each combination of strategies. The players will use strategies to maximize their payoffs, and the winner will receive a positive payoff and others will earn either negative or zero payoffs. A game is considered cooperative or non-cooperative and depends on the binding commitments of players exist or not.

In a normal competitive bidding, there is no binding commitment to all players, and the sum of their payoff (i.e., contract profit) will not be zero. This study adopted a non-zero, non-cooperative game to the bidding game framework and used the Nash equilibrium to seek the solution.

**Constructing a Prospect Game Theory Model for Bidding Decision**

The flowchart of BD-PGTM is shown in Fig. 1.

**Phase I – Preparation**

The aim of phase I is to identify the companies whom may participate the bidding, the type of bidding strategy, submitted bidding price to each bidding strategy and its implement probability.

**Data Collection**

The BD-PGTM model is applied to case studies to demonstrate the potential effectiveness of the approach in practice. In the case, three companies (A, B, and C) will participate in the competitive bid and submit a bid price. The decision makers of those companies were considered homogeneous, as all were qualified professionals in the construction field.
and had prior experience in bidding strategies and bidding procedures. The PDM of each company has decided the company’s ultimate bidding price. Company A will use BD-PGMT to forecast what bidding strategies and bidding prices that the competitors may adopted.

Determining competitive bidding strategy and profit margins

The cost estimated by each construction companies may be very similar and the variations in competitors’ bids are due mainly to their selected mark-up size. Prior to the forecasting, this study set what bidding strategies and its mark-up size the competitors would potentially adopt. The bidding strategy was classified into five categories, include S1: Lowest profit to secure the project; S2: Minimize company profit to strengthen competitiveness; S3: Average construction market profit margin; S4: Higher-than-average profit margin; and S5: highest profit margin. The company A determined the mark-up size for each bidding strategy is 3%, 4%, 5%, 7%, and 10%.

In the collected actual case, the construction cost calculated by company A was $17954×10^3 USD, and the expected profit (unit: 10^3 USD) of each bidding strategy was $538.62, $718.16, $897.70, $1256.78, and $1795.40.

Assign implement probabilities to each bidding strategy

In order to assign an implement probability for each bidding strategy to all participants, this study adopted FPR to estimate the relative importance of the bidding strategies to each participant. The linguistic terms used in FPR were AH: Absolutely important, VH: Very highly important, SH: Strongly important, WH: Weakly important, EQ: Equally important, WL: Weakly less important, SL: Strongly less important, VL: Very strongly less important, and AL: Absolutely less important. All of them are associated with real numbers {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9} to compare to corresponding neighboring factors. Five evaluators of company A adopt foregoing linguistic terms to assess the relative importance of the bidding strategy to company A, B, and C. For example, the assessment of company A were {VL, EQ, WH, SH}, {AL, WL, EQ, AH}, {VL, WL, WH, VH}, {AL, EQ, EQ, AH} and {SL, EQ, WH, AH}, via the computational process, relative weights can be calculated as {0.1086, 0.2644, 0.2964, 0.2964, 0.2491, 0.0815}. In the same manner, company A also can forecast the relative weights of bidding strategies to company B and C as {0.1146, 0.2255, 0.3059, 0.2534, 0.1006} and {0.2648, 0.3007, 0.2183, 0.1441, 0.0721}. Table 1 shows the forecasted results.

Table 1. Forecasted results of company A’s PDM

<table>
<thead>
<tr>
<th>Bidding strategy</th>
<th>Profit ($10^3 USD)</th>
<th>Probability of implementation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>538.62</td>
<td>10.86</td>
</tr>
<tr>
<td>S2</td>
<td>718.16</td>
<td>11.46</td>
</tr>
<tr>
<td>S3</td>
<td>897.70</td>
<td>26.44</td>
</tr>
<tr>
<td>S4</td>
<td>1256.78</td>
<td>34.25</td>
</tr>
<tr>
<td>S5</td>
<td>1795.40</td>
<td>7.21</td>
</tr>
</tbody>
</table>

This study assumes that the relative weight of a bidding strategy is correlated to probability of implementation.

Phase II – Obtain PDM’s preference

Goals of this section are to elicit the value function and probability weighting function of the “criterion” (Company A) to forecast the value function and probability weighting function of competitors (Company B and C).

Elicit value function and probability weighting function of criterion

This certainty equivalent method is used to elicit the value function and probability weighting function of company A’s PDM. In the method, a two outcomes (win and lose) prospect may be expressed as [x, p; 0, 1-p], with “x” representing gain of win and “p” representing the objective probability of win. The subjects (PDM of company A) will be asked to provide a certain value y(x, p), in which y(x, p)=[x, p; 0, 1-p]. It is difficulties for the subject to directly assessing the value of y, this study using the bisection method to assess the value. Table 2 shows elicited results for Company A’s PDM.

Table 2. Elicited results of company A’s PDM

<table>
<thead>
<tr>
<th>x (USD)</th>
<th>y(x)</th>
<th>p (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>100</td>
<td>75</td>
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<tr>
<td>15</td>
<td>14</td>
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<td>75</td>
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<tr>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

Substitute x, p and y(x, p) into above equation and three known conditions w’(p=0)=0, w’(p=1)=1 and v(x=0)=0, then will get:

Substitute the value function and probability weighting function in gain condition into above equation, then adopt regression analysis to obtain α=0.8932 and γ=0.7484. Fig. 3 shows the elicited value function and probable weight function of company A’s PDM.
Forecast competitor’s value function and probability weighting function

The competitive situation of contract bids makes it impossible to obtain value functions and probability weighting functions directly from competitor PDMs. This study assumes the PDM’s value functions and probability weighting functions will also adhere to the form proposed by Tversky and Kahneman. Owing to the value function and probability weighting functions for company A’s PDM are known, this study employed fuzzy rating method to evaluate the differences in emphasis on money and risk attitudes between two companies’ (competitor and company A) PDM to forecast competitors’ value functions and probability weighting function. In consider the evaluator’s rating cognition, this study first adopt five linguist variables {VL: Very low, L: Low, I: Indifference, H: High, VH: Very high} to evaluate the difference rate from -20% to 20%. This study employ a questionnaire to survey evaluators and use the fuzzy statistic analysis method to obtain a fuzzy number membership function, Fig. 2 shows the results.

![Membership function](image)

**Fig. 2. Membership function for fuzzy rating**

To forecast value function, the evaluators adopt linguistic variables to evaluate the difference ratio in the emphasis on money between competitor’s and company A’s PDM. Then apply fuzzy number’s addition operator and multiplication operator to calculate the integrated fuzzy numbers. Next, use the center of gravity method to defuzzify the integrated fuzzy numbers and the linear conversion to obtain the difference ratio in the emphasis on money. The area under the value function curve was obtain by integration the amount of money (x-axis) and the value of money (y-axis), which can represent the attitude of emphasis on money within a specific monetary range. If a competitor’s PDM places more emphasis on money than the criterion, then the area below the value function curve will be comparatively larger. Otherwise the area below the value function curve will be comparatively smaller. The difference in the area can be regarded as the difference in emphasis on money. In Fig. 3 the figure on the left shows the concept of forecast competitor’s value function. For example, company A’s five evaluators compare the PDM of company B with the PDM of company A, the evaluated results are {H, I, L, I, VH}. Through the defuzzification process, a fuzzy rating was obtained as 6.3090; by the way of linear transformation method can obtained a difference rate of 5.24%. As the area under the value function curve of company A’s PDM was 27113823, the corresponding area of company B’s PDM should be 29533484. A trial and error procedure then obtained the parameter α of value function was 0.8958. In the same manner can forecast the value function of company C’s PDM, and the parameter α=0.8857. In Fig. 3 the figure on the right shows the forecasted value function of PDMs’.

![Concept of forecast competitor PDM’s value function](image)

**Fig. 3. Concept of forecast competitor PDM’s value function and forecasted result**

In CPT, the probability weighting function is an inverse-S-curve. The intersection point between the probability weighting function and riskless line \((w(p)=p)\) is called the point of risk neutral (PRN). The shape of the probability weighting function on the left side of PRN is convex-down, which over-weights the probability \(w(p)>p\). On the contrary, the shape of the probability weighting function on the right side of PRN is concave-up, with an underweighted probability \(w(p)<p\). If risk attitude is more risk seeking than the criterion, the overweighting range will be widened and the PRN will move right. A risk attitude with less risk averse than the criterion will cause the PRN to move left. In Fig. 4 the figure on the left shows the concept of forecast competitor’s probability weighting function. This study use the same fuzzy rating process to evaluate the difference ratio of risk attitude in risk seeking between competitor’s and company A’s PDM. For example, company A’s five evaluators adopted the linguistic variables to compare the company B’s PDM with the company A’s PDM, the evaluated results are \{L, I, L, I, VL\}. Via the processes of calculating the integrated fuzzy numbers, defuzzification, and linear transformation, obtained evaluator fuzzy ratings of difference rate in risk attitude is 6.76%. The probability of PRN for the probability weighting function of company A’s PDM is 0.4043. Thus, the probability of PRN for company
B’s PDM should move to $0.4043 \times (1 + 6.76\%) = 0.4309$. Trial and error procedure was then used to obtain the parameter $\gamma$ of probability weighting function is 0.8139. In the same manner, can obtain $\gamma=0.7283$ for company C’s PDM. In Fig. 4 the figure on the right shows the forecasted probability weighting function of PDMs’.

**Phase III - Deciding bidding price**

Bidder takes the presumed strategies of competitor bidders into consideration before formulating a bid strategy and setting a bid price. This study adopts non-cooperative games to describe the analysis process and use the prospect value of each bidding strategy to represent game payoffs.

Calculate joint probability for bidding strategy combination

In competitive bidding, the bidder can adopt different bidding strategy and form bidding strategy combination. The probability of the combination achieving can be represented by the joint probability of PDMs adopted strategy. For example, the probability of companies A, B and C all adopt bidding strategy S1, the probability for this situation occurred can be calculated as $10.86\% \times 11.46\% \times 26.48\% = 0.33\%$. Table 3 shows the probability of implementation for various bidding strategy combinations.

**Table 3. Joint probability of bidding strategy combinations**

Calculate PDM’s prospect value of bidding strategy

The prospect value $V_{\text{CPT}}$ for a bidding strategy which the PDM adopted can obtain by prospect value equation. In the equation, the $v(x)$ and $w(p)$ stand for the PDM’s value function and probability weighting function. The $x$ is the expected profit of adopted bidding strategy, while $p$ is the joint probability of bidding strategy combination. Both values are elicited and forecasted in the previous section, and shows in Table 1 and Table 2. For example, the joint probability is 0.33% for the PDMs of companies A, B, and C all select bidding strategy S1. Under such a scenario, a company will earn an estimated profit of $538.62 \times 10^3$ if it wins the bid or 0 if it loses. The prospect values of PDM of Company A, B, and C are $3.8 \times 10^3$, $2.7 \times 10^3$, and $4.1 \times 10^3$. Table 4 shows the normal form of bidding game. The first entry in each cell is company A’s prospect value $V_{\text{CPT}}$ for the corresponding strategy combination, the second is company B’s, and the third is company C’s.

**Table 4. Normal form of bidding game**

Forecast competitors bidding strategies and bid prices

This study use the static non-cooperative game to forecast the PDMs adopted bidding strategies and bidding prices. The pay-off of games is the PDM's prospect value of bidding strategies, which were calculated in last section. This study adopted best-response analysis method to find the Nash equilibriums. In Table 4, the payoff set in bold face type is the Nash equilibrium. From the results of the game, this study forecast that companies A, B, and C would adopt bidding strategies S4, S4, and S2, respectively.

Comparison and Decision Making

Forecast results shows that company C’s bidding price was the lowest. Therefore, if company A wants to win the project, it should submit a bidding price lower than $18672160$ (USD).

**CONCLUSIONS**

This study develops a Prospect Game Theory Model for Bidding Decision (BD-PGTM) to help construction companies determine appropriate bidding prices. Research contributions include:

1. BD-PGTM integrates fuzzy rating, fuzzy preference relations (FPR), cumulative prospect theory (CPT) and game theory (GT), provide construction companies a systematic decision model to help them make optimal bidding strategy decisions and set appropriate bidding prices.

2. Use FPR to simplified the process of forecasting implementation probability for bidding strategies
and overcome traditional reliance on evaluator experience and guesswork.

3. Adopt fuzzy rating to forecast value functions and probability weighting functions of competitor PDMs, which may reduce inherent uncertainty in evaluator ratings and also eliminate the predicament of being unable to obtain value functions and probability weighting functions directly from competitor PDMs.

4. Use CPT to calculate PDMs’ preference values in terms of value functions and probability weighting functions for assigned mark-up scales and implemented bidding strategy probabilities based on prior forecasts.

5. Adopt Game Theory to analyze PDM-determined bidding strategy. Analysis’s results allow Company A to set an optimal bidding price able to secure both the contract award and as high a profit as possible.

6. This study validated the BD-PGTM using actual bidding projects obtained from construction companies in Vietnam and successfully helped the PDM to decide on optimal bidding prices.

References
Data mining and statistical analysis of construction equipment failure

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**Purpose** Construction equipment is a key resource, and contractors that own a large equipment fleet take all necessary measures to maximize equipment utilization and minimize equipment failures. Although most contractors implement scheduled maintenance programs and carry out periodic inspections and repairs on their construction equipment, it is still difficult to predict the occurrence of a specific failure of a piece of equipment in the short or long term. According to a survey in the United States, approximately 46% of the major equipment repairs was undertaken as a result of an unexpected failure. Although it is not possible to predict all failure events, a slight improvement in their prediction represents a significant saving in time and cost for a large contractor. Statistical power law models and data-mining models were compared to investigate their pros and cons in predicting critical failure events of heavy construction equipment.

**Method** With large amounts of equipment failure data accumulated in a surface mining project, two different types of failure models were created for comparative analysis from a practical point of view. For selected equipment units, failure data were collected along with the relevant factors which may cause variations of equipment failure rate (or mean time to failure). In a classical approach, Power law models of equipment failure rates are fitted using RGA 7.0; while in the data-mining approach, the mean time to failure is modeled using a data-mining algorithm-decision tree induction, establishing logical, mathematical, and statistical relations between MTTF (Mean Time Between Failures) and its various factor of impact (equipment conditions, failure history, environmental conditions, etc.). Both models are used for validation tests on randomly selected time periods and compared in terms of their performance. **Results & Discussion** The two types of models were compared.

**Keywords:** equipment management, failure analysis, data mining, decision support

**INTRODUCTION**
Construction equipment is a key resource, and contractors owning large equipment fleet take all necessary measures to maximize the equipment utilization and minimize the equipment failures. Although most contractors implement scheduled preventive maintenance programs and carry out periodic inspections/repairs on their construction equipment, it is still a difficult task to predict the occurrence of a specific failure event for a piece of equipment in the short or long term. According to a survey in the United States, approximately 46% of the major equipment repairs followed upon an unexpected failure. As a result of such breakdowns, the equipment unit has to be pulled out of production and repaired on site, or brought to a shop for repair. In addition to the impact on the project, other problems arise from these unexpected failures, include high costs for emergency repairs on a remote jobsite, and high storage-costs for a large number of spare parts. Although it is not possible to predict all failure events, a slight improvement in their prediction represents a significant saving in time and costs for a large contractor. This paper addresses the predictive analysis on the major failures (critical and catastrophic ones) of construction equipment for a contractor. With large amounts of equipment failure data accumulated in a surface mining project, two different types of failure models are created for comparative analysis from a practical point of view, i.e. classical time-dependent power law models, versus generic time series models. For selected equipment units, their failure data are analyzed along with the relevant influencing factors which may cause variations of equipment failure intensity (or mean time between failures). Through a large number of experimental tests on equipment reliability analysis, it is concluded that classical power law models are easy to apply and are capable of predicting reliability metrics at both the system and subsystem levels of an equipment system with fair results, yet time series models based on predictive data mining algorithms are more flexible, comprehensive, and accurate by taking various influencing factors into account in reliability analysis.

The contributions of the paper are two folded: first, relevant issues are discussed on applying generic...
predictive data mining models to time series analysis of equipment reliability, its advantages and disadvantages; second, a systematic comparison is made between classical power law models and generic time series models in terms of their performance and usability in forecasting equipment reliability metrics.

RELATED WORKS
According to Vorster (2004; 2005), construction equipment involved in any civil engineering and mining works must be managed to minimize unscheduled downtime. Equipment age, reliability, and the repair/maintenance costs are closely related and should be balanced constantly; repair before failure is more cost effective than crisis-based run-to-failure; scattered breakdowns at random inconvenient times have larger impact on planning and activity. If reliability metrics can be predicted with a fair level of accuracy, the decisions on equipment maintenance and repairs can be optimized to reduce on-shift emergency repairs. Smith and Oren (1980) also points out that system reliability estimate strongly influences predicted profitability and customer acceptance.

Reliability is the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions (Ebeling 1997), although it is difficult to predict the time at which a piece of equipment fails due to the inherent uncertainties of failure events and multiple factors of impact, the time-dependent failure events demonstrate some statistical rules and the patterns of trend. Duane proposed the power law model on the failures of a complex repairable system; the accumulated MTBF is linearly related to the operating time on log-log scale [Duane 1964]. Barabady and Kumar (2008) used various statistical distributions including Weibull, exponential, normal, and log normal distribution to analyze the reliability of a crushing plant, in order to identify the bottlenecks in the system and to find the components or subsystems with low reliability for a given designed performance.

Time series is a series of sequenced observations of event data, usually taken in equally spaced time intervals. The theories used for time series analysis have been used for reliability analysis and forecasting of a complex system. For examples, Ho and Xie (1998) used the classical time series analysis method of ARIMA for predicting the number of failures of a mechanical system; Hong and Pai (2006) used Support Vector Machine (SVM), a machine learning algorithm for predicting engine reliability, comparisons were made with power law models, ARIMA, General Regression Neural Network (GRNN) models in terms of their prediction performance. The researchers concluded that, compared with the power law model, time series models can depict the nonlinear complex relationship among the reliability metrics and these other observations in reliability performance.

PROBLEM STATEMENT
A contractor’s equipment fleet is working on an oil sand mining project on 3-shift schedule around the clock. Among the equipment fleet are dozers, graders, trucks, backhoes etc. The contractor has a team of operators, superintendents, project managers working on the jobsite and keeping full working records of downtime, uptime, failure events, and repair details on each unit. Apart from the preventive maintenance and scheduled overhauls, there are unscheduled random failures on each equipment unit. The contractor is keen to predict the reliability of each unit so that better decisions on allocations of equipment and maintenance resources can be made for scheduling purpose. Although traditional reliability theory can be applied to the heavy equipment in service, there are practical obstacles which make it difficult to apply these reliability modeling techniques originally developed from manufacturing industry; the construction environment is highly uncontrollable with constantly changing weather conditions, job natures, and operating conditions, all of which have an impact on the equipment reliability. Each unscheduled critical failure leads to an emergency repair case and causes interruptions to construction works with various financial impact; under some critical failure circumstances, the equipment cannot be repaired on the jobsite and must be brought to a distant shop for extensive repairs.

The contractor has accumulated many years of equipment reliability data along with their history of maintenance and repairs, failure data contains such information as (1) Equipment description: equipment identification, type, model, sub-systems, year of manufacture, odometer and hour meter readings; (2) Equipment downtime and uptime: equipment shutdowns for emergency repairs, scheduled preventive maintenance and overhaul events; (3) Equipment repair details: class of failures, reason down, work done, maintenance personnel (mechanics, electricians, welders, etc.), working hours, locations. Sample reliability data of a piece of equipment is shown in Table 1.

Construction equipment is a complex system comprising of various subsystem: engine, braking system, hydraulic system, undercarriage, etc., these subsystems and components have different economic lives and different reliability metrics; they are not completely independent and must be kept in working conditions and work in coordination for the equipment to function properly. For each equipment unit,
the contractor is interested in predicting the equipment reliability metrics for the planning period, such as rate of failures, reliability level for the scheduled mission, availability, time between failures, length of uninterrupted working hours without failure given a minimum reliability level. Predictions at both system level and subsystem levels are desired for management decisions for the upcoming planning periods.

Table 1. Sample reliability data of an equipment unit in the field

<table>
<thead>
<tr>
<th>Time</th>
<th>Name</th>
<th>Trade</th>
<th>Class</th>
<th>Reason Down</th>
<th>Status</th>
<th>Time Up</th>
<th>Work Done</th>
<th>Down Time</th>
<th>Location</th>
<th>Skill Set</th>
<th>Workforce</th>
<th>Contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/07/01</td>
<td>HISC</td>
<td>MECH</td>
<td>Steamm</td>
<td>STEAM FOR P2 SERVICE</td>
<td>UP</td>
<td>01/07 /01 08:22</td>
<td>3401 COMPLETED STEAMING.</td>
<td>3.35</td>
<td>Steam Bay</td>
<td>HD Mechanic</td>
<td>Polar Air</td>
<td>Steam Bay Contractor</td>
</tr>
<tr>
<td>01/07/01</td>
<td>AC-TIN</td>
<td>MECH</td>
<td>Service</td>
<td>P2 SERVICE</td>
<td>UP</td>
<td>01/07 /01 13:09</td>
<td>3302 SERVICE COMPLET-ED.HRS.4782./WO.3 97905 REPLACE</td>
<td>4.77</td>
<td>Shop</td>
<td>HD Mechanic</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>01/07/03</td>
<td>HERR</td>
<td>MECH</td>
<td>Air Conditioning</td>
<td>AIR CONDITIONING - POLAR AIR</td>
<td>UP</td>
<td>01/07 /03 11:48</td>
<td>PRESSURE TESTED &amp; RECHARGED</td>
<td>1.38</td>
<td>Field</td>
<td>HD Mechanic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>01/07/04</td>
<td>MCCA</td>
<td>MECH</td>
<td>Service</td>
<td>ENGINE OIL DIPSTICK</td>
<td>UP</td>
<td>01/07 /04 01:15</td>
<td>RPD ENGINE OIL DIPSTICK, TRANS OIL FILTER DIPSTICK</td>
<td>0.25</td>
<td>Field</td>
<td>HD Mechanic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>01/07/17</td>
<td>KOST</td>
<td>MECH</td>
<td>Service</td>
<td>FIELD SERVICE</td>
<td>UP</td>
<td>01/07 /17 13:20</td>
<td>COMPLETED HOURS 5165</td>
<td>0.33</td>
<td>Field</td>
<td>HD Mechanic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>01/07/17</td>
<td>ANTH</td>
<td>MECH</td>
<td>Repair Light</td>
<td>HEADLIGHTS NOT WORKING</td>
<td>UP</td>
<td>01/07 /17 22:00</td>
<td>REPAIRED WIRING FOR HEADLIGHTS</td>
<td>0.17</td>
<td>Field</td>
<td>HD Mechanic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>01/07/19</td>
<td>RYAN</td>
<td>MECH</td>
<td>Service</td>
<td>CHANGE OILS FINAL DRIVES</td>
<td>UP</td>
<td>01/07 /19 12:14</td>
<td>COMPLETED</td>
<td>3.23</td>
<td>Shop</td>
<td>HD Mechanic</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>01/07/19</td>
<td>FOY</td>
<td>MECH</td>
<td>Air System</td>
<td>NO POWER</td>
<td>UP</td>
<td>01/07 /19 14:20</td>
<td>REPAIR ENGINE AIR FILTER</td>
<td>0.33</td>
<td>Field</td>
<td>HD Mechanic</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

In addition, the project manager needs to identify these frequent failures (failures occur frequently and periodically), cascading failures (one failure causes another), underlying failure causes, and opportunities for improvement.

The predicted reliability metrics can help to optimize the scheduled maintenance of equipment. For examples, preventive maintenance can be rescheduled to reduce failures in service; overhaul decisions can be made to avoid frequent or major failures; maintenance crew and other resources can be properly allocated; equipment can be assigned to the projects according to their predicted performance and project characteristics.

**POWER LAW MODELS AND EQUIPMENT RELIABILITY ANALYSIS**

A piece of construction equipment is considered as a fielded system comprised of many subsystems, components or assemblies with different reliability performance and life cycles. Critical failures of any of them can lead to equipment shutdowns on shift, and failed components must be fixed to bring the equipment back to work as soon as possible. The overall equipment system follows a “failure-fix-failure” cycle during operations.

The failure rate of a piece of construction equipment follows a typical “bathtub” curve: the new equipment experiences a burn-in stage with decreased rates of failure in the first half or one year, and then becomes stable in reliability; when the equipment ages, the wear-out stage is entered with increasing rates of failures. Although it is possible to judge the stages of the equipment based on the past experience and recommendations from the manufacturer, the transition point of stages or even the whole life cycle of the equipment varies to a large degree depending on such conditions as the design and manufacturing reliability, equipment use, degree of care and maintenance, repair history etc. As a result, the most reliable approach to identify the three stages of an equipment unit and make predictions on its performance is to perform reliability analysis on its life-to-date failure data.

A power law model indicates that the failures of a complex system are time dependent and follow a Non Homogeneous Poisson Process (NHPP). The power law model was first proposed by Duane in...
1962 to describe the failures of a complex system at the stage of development (repeated design tests and improvement in reliability). Duane found that the accumulated MTBF of a system (if the repair time of the system is small compared with MTBF) has a linear relationship with the time if plotted on a log-log paper, with the slope indicating the trend of changes in failure intensity. The power law model could also be used to describe the change of reliabilities of a fielded system in service and make predictions on the failure rates in the upcoming decision periods.

For a unit of construction machine under the policy of minimum repair (just conduct minimum repair to bring the machine back to work), the system failure intensity function can be expressed by a power law model as below:

\[ \lambda(t) = \beta t^{\beta - 1} \] \[ \text{[1]} \]

If \( \beta = 1 \), the instantaneous failure intensity is a constant, the equipment has stable reliability; if \( \beta < 1 \) the equipment is in the burn-in stage, and if \( \beta > 1 \) the equipment is in the wear-out stage. Therefore the power law model is a generalization of the homogeneous Poisson process (HPP, Weibull distribution) and allows for change in the intensity function as a repairable system ages [Reliasoft 2012].

For each equipment unit, MTBF is calculated as the accumulated equipment operating time \( t \) divided by the accumulated number of failures up to time \( t \): MTBF = \( t / N(t) \). MTBF is then plotted against the operating time \( t \) on a log-log scale paper, which should be approximately a straight line according to the principle of a power law model. An expert tool, RGA 7 by Reliasoft (2012) is used for calculation of best fit line and plotting. Figure 1 shows the MTBF versus time plot for a D11 dozer. It is noticed that although a straight line can be used to fit failure data at the system level, some noisy data exists, due to influences on the arrival pattern of equipment failures from some external factors. This power law plot also shows clearly the equipment MTBF is decreasing with time as this piece of new equipment grows in reliability.

TIME SERIES MODELS AND EQUIPMENT RELIABILITY ANALYSIS

Time series data is a sequence of observations taken at equal intervals of time. The purpose of collecting and modeling time series data is to identify the change patterns in data and to forecast the future values assuming the current trend continues. Many reliability metrics of construction equipment can be modeled as time series data, including reliability (%), number of failures, mean time between failures; all these metrics change with consecutive time periods of equipment operations. If reliability variation of a piece of equipment can be captured in a time series model, its future values can be forecasted based on the history of reliability data and related factors of impact.
ARIMA models
Traditionally time series data is analyzed by breaking down into four components (Box and Jenkins 1994): (1) Trend movement, which is the general direction in which a time-series is moving over a long interval of time; (2) Cyclic variations, being the long-term oscillations of the time series about trend; (3) Seasonal variations, which are the seasonal movements of the time series; (4) Irregular variations, which are variations of the time series due to random shocks. AutoRegressive Integrated Moving Average (ARIMA) model is the traditional forecasting method for time series analysis first proposed by Box and Jenkins. In ARIMA (p,d,q) model, a time series data is decomposed into autoregressive (the current value is correlated to the previous p lagged values of the time series), and moving average (the current observation shows random shock from the previous q lagged values of the time series) after integration (differentiation of a time series to make it stationary) if necessary. Seasonal variations and influences from other relevant time series or some intervention variables can also be modeled yet their use is difficult due to requirements on visual judgment and complex statistical tests.

(a) Drive system

(b) Engine

(c) Undercarriage

(d) Air system

Fig. 2. MTBF versus time plot of selected subsystems of a D11 Dozer
Table 2. Prediction results of MTBF and number of failures of D11 Dozer using power law model

<table>
<thead>
<tr>
<th>Period</th>
<th>Actual MTBF</th>
<th>Predicted MTBF</th>
<th>Error</th>
<th>Actual number of failures</th>
<th>Predicted number of failures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper (90%)</td>
<td>Estimated</td>
<td>Lower (90%)</td>
<td></td>
<td>Upper (90%)</td>
</tr>
<tr>
<td>95</td>
<td>107.13</td>
<td>49.77</td>
<td>44.15</td>
<td>38.87</td>
<td>-62.99</td>
</tr>
<tr>
<td>96</td>
<td>110.37</td>
<td>49.69</td>
<td>44.08</td>
<td>38.81</td>
<td>-66.28</td>
</tr>
<tr>
<td>97</td>
<td>73.42</td>
<td>49.62</td>
<td>44.02</td>
<td>38.75</td>
<td>-29.40</td>
</tr>
<tr>
<td>98</td>
<td>194.38</td>
<td>49.55</td>
<td>43.96</td>
<td>38.70</td>
<td>150.43</td>
</tr>
<tr>
<td>99</td>
<td>188.68</td>
<td>49.48</td>
<td>43.89</td>
<td>38.64</td>
<td>-144.79</td>
</tr>
<tr>
<td>100</td>
<td>9.52</td>
<td>49.41</td>
<td>43.83</td>
<td>38.59</td>
<td>34.31</td>
</tr>
</tbody>
</table>

Time series analysis using predictive data mining models

As a substitute to the classical ARIMA family of models, predictive data mining algorithms can be used to explore the relationship among the data in time series, relevant time series, and intervention variables in a generic expression:

\[
Y_t = f\left(\{Y_{t-1}, Y_{t-2}, \ldots, Y_{t-n}\}, X_{(i-t-j)}, X_{(i-t-j)}, \ldots, X_{(i-t-n)}\right) + \epsilon_i
\]

Where
- \(Y_t\) — Current observation
- \(Y_{t-i}\) — Previous n observations, i=1,2,...,n
- \(X_i\) — Related time series or invention variable i
- \(X_{(i-t)}\) — historical observations of related time series or invention variable at (t-j)
- \(n_i\) — correlated lagged values of related time series or invention variable i
- \(\epsilon_i\) — residual of the fitted model

Eqn [2] is a generic expression of using predictive data mining models for time series analysis; there are many data mining algorithms that can be used to explore this underlying relationship in time series data including decision tree, multilayer back propagation neural network, general regression neural network, gene expression programming, etc., and ARIMA (p,d,q) model can be considered as a special case of assuming linear relationship among variables. In general situations, the model in eqn [2] can be represented in combined logical, mathematical, and statistical forms in order to best describe the knowledge hidden in reliability data. See Han and Kamber (2006), Larose (2005) etc., for details on various predictive data mining algorithms.

Compared with the general prediction problems, time series analysis using predictive data mining algorithm has an important feature of autoregression and dependence with the historical observations of related time series and intervention variables, as shown in Eqn [2]. The lagged values of both the time series and relevant time series are used as surrogate variables in the model, and the numbers of these lagged variables are selected using information criteria such as how much the inclusion of a lagged variable in the model helps to improve the overall model fit to the time series data. The algorithm of regression tree induction is presented in this paper to compare with the power law models.

Regression trees models

Regression trees are learned from data to reflect the postulated relationship between the predicted values and their predictors. This is a supervised learning process: in time series data, if the current observation is to be predicted, all the other determinants, including previous “n” observations, correlated time series, correlated factors or perturbation events, are used as a collection of data space for computer to learn the tree structure.

The regression tree algorithm works as below: the algorithm searches over the data space and recursively partitions it into subspace, where more pure information or promising relations can be found. For example, the regression tree can use a measurement such as information gain or chi-square test to search for most information-rich splitting of data space by an input variable as well as a split-on value so that the partitioned data space contains purer information on the prediction results. At each partitioned data space a regression model is built to predict the outcome.

Model training, validation and forecasting

Mean Time between Failures (MTBF) of equipment is computed on a weekly basis, and the regression tree model is learned automatically from the data collected over a two year period. Apart from the MTBF data series, Mean Time to Repair (MTTR), preventative maintenance (PM) data series are used
as predictor series, and overhaul event is modeled as an intervention variable ("1" for overhaul, and "0" for none) in the predictive data mining model. Regression tree model of a D11 dozer is presented here for illustration purpose. Fig. 3 shows the first three levels of the derived regression tree model, each node at a lower level containing more consistent information on MTBF. Tree splitting criteria is learned from data and attached to the bifurcation of tree branches, for example, “Whether the previous MTBF is more than 132.987 hrs” is the first splitting criterion, and “whether time is before Week #74” is used as second criterion for further splitting of nodes into child notes, and so on. Each leaf node contains a regression formula for MTBF forecasting.

The MTBF time series model is validated by reserving 10% of the collected data. Forecasted values and actual values are compared with part of the results shown in Fig. 4 and Tab. 3. As seen in Fig. 4, the trend of MTBF variation with time is also detected by the algorithm.

Time series forecasting results on MTBF and number of failures are shown in Tab. 3 for comparison with these results from the power law model in Tab. 2. The accuracy of forecasting is improved substantially by using predictive data mining models. The power law model tends to take the mean values with a little consideration to the overall trend, however the time series model can follow both the long term trend and short term variations.

Fig. 3. Regression Tree model for forecasting Mean Time between Failures (MTBF) of a D11 Dozer

Table 3. Validation on forecasting of MTBF (part of results)

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean Time between Failures (MTBF)</th>
<th>Number of Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual (hrs)</td>
<td>Predicted (hrs)</td>
</tr>
<tr>
<td>95</td>
<td>215.78</td>
<td>158.34</td>
</tr>
<tr>
<td>96</td>
<td>126.6</td>
<td>121.74</td>
</tr>
<tr>
<td>97</td>
<td>205.63</td>
<td>169.05</td>
</tr>
<tr>
<td>98</td>
<td>124.65</td>
<td>122.22</td>
</tr>
<tr>
<td>99</td>
<td>209.03</td>
<td>166.98</td>
</tr>
<tr>
<td>100</td>
<td>166.78</td>
<td>120.98</td>
</tr>
</tbody>
</table>
COMPARISON OF POWER LAW MODELS AND PREDICTIVE DATA MINING MODELS

Both power law models and time series models can be used for forecasting of reliability metrics of construction equipment, their pros and cons are summarized in Tab. 4 from different perspectives.

<table>
<thead>
<tr>
<th></th>
<th>Power law models</th>
<th>Time series models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data requirements</strong></td>
<td>Medium to large</td>
<td>Very large</td>
</tr>
<tr>
<td><strong>Ability to account for factors of impact</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Assumption</strong></td>
<td>Non Homogeneous Poisson Process, random failure process with different intensities at different stages of equipment life</td>
<td>Data series with underlying patterns caused by both randomness and a large number of influencing factors, both internal and external</td>
</tr>
<tr>
<td><strong>System and sub-system level modeling</strong></td>
<td>Easy</td>
<td>Difficult to model at subsystem level due to sparse data</td>
</tr>
<tr>
<td><strong>Modeling</strong></td>
<td>Fit data into a NHPP process model (extended Weibull distribution)</td>
<td>Use complex computer algorithm to find potential trends, rules and patterns from reliability data</td>
</tr>
<tr>
<td><strong>Detecting changes of failure patterns</strong></td>
<td>Yes, to a limited degree</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Complexity of model</strong></td>
<td>Low</td>
<td>Medium to high</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Moderate to relatively high</td>
<td>High</td>
</tr>
</tbody>
</table>

CONCLUSIONS

A reliable fleet of construction equipment is critical to the success of heavy construction projects. Contractors can make informed decisions on equipment maintenance, repairs, replacement if the reliability of equipment can be well understood and future metrics can be forecasted with a satisfactory level of accuracy. Analysis on the field reliability data provides firsthand fact-based information on equipment failure trends, regular and irregular patterns, as well as underlying causes. Classical power law models and predictive data mining based time series models are compared in forecasting equipment reliability metrics in this paper.

The classical power law models can be applied conveniently to reliability analysis with solid statistical foundations, the simple time-dependent NHPP model is able to identify the changing trends in equipment reliability and predict the reliability metrics of equipment in the planning horizon. However the time series models based on predictive data mining algorithms are more flexible and powerful in creating forecasting models with due consideration to the influencing factors of reliability. Although the data mining algorithms are complex in implementation, there are commercial data mining tools available for explorative analysis through their user-friendly interfaces, model visualization, and interactive features.

Although predictive data mining models can automatically sift through reliability data for pattern recognition, it requires large amount of reliability data in order to produce valid results, which might be difficult for a single piece of equipment within its history of operations in some situations. On the contrary, power law models can make good prediction results under such circumstances, what is more, reliability of the subsystems of the equipment, more desirable by the maintenance crew, can also be predicted using power law models if there is a minimum number of data ensuring statistical significance.

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References


Suction force of blowing fans on various surface shapes of outer wall

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Purpose The outer walls of high-rise buildings contain many grooves of irregular shapes and sizes. Conventionally, gondola systems on platforms are used to carry the workers who conduct maintenance work on the outer walls of high-rise buildings. It is very difficult to perform such works on outer walls using a gondola due to external disturbances such as squalls. Therefore, we propose a stable attachment for a grooved wall surface; with an air suction force of a fan, it is possible to generate enough force to attach onto the wall surface. In this paper, a test apparatus was developed to measure the attaching force of a suction fan according to fan speed. Also, the suction forces were measured according to four types of wall surfaces. Method A test rig for suction force was developed to measure the attaching force of the suction fan. Using this test rig, four kinds of specimens were compared by measuring the attaching force. The test rig consisted of a pneumatic cylinder, a load-cell, and a rotating speed meter. Four different vertical walls surfaces were made: flat, step, rib and embossing type surfaces. The suction fan housing was fixed by a frame when the fan rotated. The wall specimen was moved by a pneumatic cylinder, and then the separation force was measured using a load cell. For each of the vertical wall types, the attaching force of the suction fan was measured at varying the rotation speeds. Results The maximum attachment force of the suction fan was 3.2 times higher on the flat surface than on the step surface at 700 rpm, 1.3 times higher on the embossed surface at 1400 rpm, and 1.3 times higher on both flat and rib surface at 1800 rpm. The maximum attachment force increased linearly according to the motor rotating speed. These results clearly show that the attachment performance of the fan is considerably less influenced by the groove of surface than by increases in the fan rotation speed.

Keywords: suction, suction fans, high-rise building, vertical outer wall, test rig, gondola cage

INTRODUCTION Typically, most robots vertically moving or climbing in concrete wall or glass have used the vacuum force to grab on surface of the wall. Many researchers have been developing on robot travelling and working on the vertical surface, and the robots are practically used attaching force of suction pads to attach the wall. Dong Gwang L., et al. developed and tested a robot system using vacuum suction technology for cleaning the window panes of a building’s outer walls¹. Kun Chan S., et al. designed a suction unit for a robot system which can climb up irregular vertical surfaces². Siyoul J conducted a study on the design of a vacuum suction pad which can provide a uniform contact shape in large-scale imprinting³. Guido La Rosa et al. developed a low-cost and lightweight robot system which can travel in a vertical direction using eight suction cups⁴. The NINJYA BIPED developed by Nishi al Miyazaki can travel along a wall’s surface using small suction cups⁵-⁷. Hwang Kim et al. developed a robot system which can travel along vertical walls stably and continuously, using endless tracks attached with vacuum pads⁸. However, robots traveling on vertical walls have limitations in terms of the shape of the walls and their adhesive force⁹-¹¹. The vacuum suction pads used in preceding studies for movement and works on vertical walls are lightweight, making them easy to use in various applications. However, attaching performance of the vacuum pad for grooved surfaces might be lower comparing with flat surface¹². Surfaces of buildings require cyclical maintenance such as repair, cleaning and painting. Normally, gondola systems boarding the workers have been used as maintenance tool on the buildings. However, as the building’s height is recently higher, working risk also rises and the maintenance robot of gondola type is needed to be developed. Because the gondola easily tends to sway around in the wind, it is difficult for the robot to carry out precision works such as painting. Even in an environment without an external load such as wind, the gondola platform has to be fixed onto a surface to perform such works as sweeping or painting. To perform these kinds of work on outer walls using gondolas, stable attachment
force to the wall is required, taking into consideration the external loads and self-load. Though suction pads used in above-mentioned papers is possible to be applied to an attaching tool on the vertical surface, in various surfaces of the latest buildings, especially in grooved walls, suction force of the pads is not always steady.

A fan has been largely installed in pipe line or duct to control the air circulation and the heat. Air suction force of the fan is possible to use attaching force on the wall surface.

In this paper, to verify performance of the fan instead of vacuum pad as attaching unit of vertical wall, a test apparatus was developed to measure the attaching forces of suction fan. Four types of wall surface shapes are fabricated to test the performance of the fans in the grooved surface. And, the suction forces of two suction fans which have different housing shape and similar motor capacity were measured and analyzed.

**WALL SAMPLES**

To simulate the various wall shapes of high-rise buildings, four types of wall samples - including flat, step, rib, and embossing shapes- were prepared. The grooved wall samples were fabricated as shown in Fig. 1. Sample size for the suction fan is 980 mm(H) × 980 mm(L) × 70 mm(D). In case of step, rib and embossing type specimen, groove depth is 30 mm. In case of rib and embossing type specimen, distance of embossed and engraved part is 40 mm. Otherwise, sample size for the vacuum pad is 500 mm(H) × 500 mm(L) × 50 mm(D). In case of rib, the distance of embossed and engraved part is 40 mm. For embossing type, distances of embossed and engraved part are respectively 40 mm and 20 mm.

**TEST EQUIPMENT**

Test apparatus to measure attaching force of the suction fan on concrete sample surface was manufactured. Main components of the apparatus compose of pneumatic cylinder, load cell, and concrete wall as presented in Fig. 2. Actual manufactured test equipment shows in Fig. 3. The specifications of the sub-components of the test equipment are presented in Table 1.

The fan is installed in the fan-housing which is fixed by metal frame. The pneumatic cylinder, which also is fixed by metal frame, functions as traveling the wall sample in the vertical direction against the suction fan. If the wall moves by the cylinder under the condition the suction fan is absorbed on the wall, load cell between the wall and cylinder is loaded to tensile force. And calculating load value of load cell is same as suction force of the fan.

![Fig.2. Schematics of test equipment for suction fan](image)

![Fig.3. Test equipment for suction fan](image)

<table>
<thead>
<tr>
<th>Table 1. Specifications of the sub-components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contents</strong></td>
</tr>
<tr>
<td>Load cell</td>
</tr>
<tr>
<td>Pneumatic Cylinder</td>
</tr>
<tr>
<td>Compressor</td>
</tr>
<tr>
<td>DAQ</td>
</tr>
</tbody>
</table>

![Fig.1. Shapes of wall surfaces. (a) Step. (b) Rib. (c) Embossing](image)
Two types of the suction fans are applied to the test apparatus. A-type suction fan has the fan-housing of cylinder shape with diameter of about 600 mm, and the rubber pad is installed in the rim of the fan-housing and functions as buffer from the wall when contacting as shown in Fig. 4. The maximum rotating speed of the fan is 1,800 rpm. B-type suction fan has the fan-housing of cylinder shape with diameter of 614 mm, but the end shape of the fan-housing is a square 667 mm on a side as shown in Fig. 5. The square end has rigid brush of 100 mm length unlike A-type. The maximum rotating speed of the fan is 1,725 rpm.

**TEST PROCEDURE**

The suction performance test of the fans was conducted according to the following procedures: 1) Install the suction fan and wall specimen 2) Operate the suction fan after regulating fan rotating speed. 3) Move the concrete wall sample to fan-housing using the pneumatic cylinder. 4) Attach the fan-housing to wall surface by suction force of the fan. 5) Move the sample in the reverse direction of fan-housing by injecting compressed air into the cylinder. 6) Increase the air pressure in cylinder until detaching completely the sample from the fan-housing. 7) Repeat the test on regulating fan speed and changing the surface walls. During the test, measuring values for load between cylinder and wall, cylinder air pressure, and displacement of wall specimen from the wall are continuously monitoring and saving to the computer.

**TEST RESULT**

The maximum suction forces of the two fans for each surface sample with motor rotating speed are shown in Fig. 6. The maximum suction force of A-type is 231.9 N with flat and rib type in 1,800 rpm, and B-type is 142 N with flat and rib type in 1,725 rpm. The maximum forces per area of the fan for the four samples that is flat, step, rib, and embossing type are respectively 820.2 N/m², 630.3 N/m², 820.2 N/m², and 708.1 N/m² for A-type and 324.9 N/m², 313.4 N/m², 337.5 N/m², and 319.6 N/m² for B-type. Results on the maximum suction force per area are presented in Fig. 7. The maximum suction force for each surface sample increased linearly with rotating speed. An Average of the maximum suction forces per area for all the samples in same rotating speed is 90.5 N/m² in 700 rpm, 494.4 N/m² in 1400 rpm, and 744.7 N/m² in 1800 rpm for A-type as presented in Table 2, and 167.5 N/m² in 863 rpm, 225.3 N/m² in 1,294 rpm, 250.1 N/m² in 1,438 rpm and 306.3 N/m² in 1,725 rpm for B-type as presented in Table 3.

**CONCLUSION**

In this study, testing equipment was constructed respectively to test and measure the attachment performance of two suction fans on various configurations of wall surface, i.e., flat, step, rib, and embossing types, formed with concrete material. The attachment performance means a degree of withstanding on the surface against external force, and is evaluated by measuring tensile force of the load cell when the fan attaching on the surface is detached by the air cylinder.

The testing equipment was designed to allow to change of the concrete wall sample and to measure both the vertical and horizontal attachment forces. The maximum suction force of A-type suction fan is 1.6 times higher than B-type. In case of A-type, a change of the maximum suction force with rotating speed is greater than B-type, and so do the change of the maximum suction force with surface shapes.

In two result graphs of Fig. 6, the slope of A-type is 2.23 times greater than B-type in flat surface. Especially, the maximum standard deviation for data of the maximum suction force is 1,043 for A-type and is 144.8 for B-type. These results show that though A-type fan is possible to get a higher suction force than B-type, it is difficult to stable suction force for various surface shapes. If the regular suction force is needed on the building outer-wall work without reference, B-type suction fan is the better for it. On flat surface, B-type suction fan could get always the maximum suction force, average maximum suction force decreased according to order of flat, rib, step and embossing shape. The results showed the fan suction force decrease as the gap of contact parts between the wall surface and the fan housing is larger.
Fig. 6. Maximum suction force for suction fan

(a) A-type

(b) B-type

Fig. 7. Maximum suction force per area for suction fan

Table 2. Test results of A-type fan

<table>
<thead>
<tr>
<th>Wall shape</th>
<th>Fan Speed</th>
<th>Flat</th>
<th>Step</th>
<th>Rib</th>
<th>Embossing</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>700</td>
<td>46.3</td>
<td>14.6</td>
<td>17.1</td>
<td>24.4</td>
<td>Flat</td>
<td>25.6</td>
</tr>
<tr>
<td></td>
<td>1,400</td>
<td>153.8</td>
<td>117.2</td>
<td>131.8</td>
<td>156.3</td>
<td>Embossing</td>
<td>139.8</td>
</tr>
<tr>
<td></td>
<td>1,800</td>
<td>231.9</td>
<td>178.2</td>
<td>231.9</td>
<td>200.2</td>
<td>Flat &amp; Rib</td>
<td>210.6</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>144.0</td>
<td>103.33</td>
<td>126.93</td>
<td>126.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td>0.167</td>
<td>0.148</td>
<td>0.192</td>
<td>0.163</td>
<td></td>
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</tr>
</tbody>
</table>

Table 3. Test results of B-type fan

<table>
<thead>
<tr>
<th>Wall shape</th>
<th>Fan Speed</th>
<th>Flat</th>
<th>Step</th>
<th>Rib</th>
<th>Embossing</th>
<th>Maximum</th>
<th>Average</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>863</td>
<td>78</td>
<td>73</td>
<td>76</td>
<td>71</td>
<td>Flat</td>
<td>74.5</td>
</tr>
<tr>
<td></td>
<td>1,294</td>
<td>105</td>
<td>96</td>
<td>102</td>
<td>98</td>
<td>Flat</td>
<td>100.3</td>
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<tr>
<td></td>
<td>1,438</td>
<td>116</td>
<td>106</td>
<td>114</td>
<td>109</td>
<td>Flat</td>
<td>111.3</td>
</tr>
<tr>
<td></td>
<td>1,725</td>
<td>142</td>
<td>128</td>
<td>142</td>
<td>133</td>
<td>Flat and Rib</td>
<td>136.3</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>110.25</td>
<td>100.75</td>
<td>108.50</td>
<td>102.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td>0.073</td>
<td>0.063</td>
<td>0.076</td>
<td>0.071</td>
<td></td>
<td></td>
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</table>
The results disclosed in this paper could serve useful information when determining the specifications of suction fan or vacuum pad to be used in gondola or robot systems for work on a building’s outer walls. However, further tests should be conducted about horizontal attachment force or attachment force with change of load rate in suction fan for various performance evaluations of attachment tools.

ACKNOWLEDGMENT
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References
Integrating of optimization and data mining techniques for high-speed train timetable design considering disturbances

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Purpose The Taiwan high-speed railway (THSR) system plays an important role in maintaining efficient transportation of passengers around Taiwan. However, the control mechanisms of THSR and the traditional railway systems are quite different. Drivers on THSR-trains cannot control the cars by themselves; only the control center of THSR can give the commands, which are based on the train timetables and should be followed by the drivers to operate the cars. Moreover, when a disaster occurs, the control center needs to prepare a rescheduled timetable in accordance with current situations that drivers can follow. Method This study presents a methodology to establish a set of optimal operation rules which are tree-based rules for real-time train timetable control for the THSR-system. The rules can be used to determine the optimal real-time operation during disturbances. Steps of the proposed methodology involve: (i) building of train timetable optimization model, (ii) generation of optimal input-output patterns, and (iii) extraction of tree-based rules for designed scenarios using the decision-tree algorithm. Results & Discussion The model could generate a timetable result that was as good as a real timetable. This means it has potential as a simulation analysis for predicting the effect of disruptions on the timetable without doing the real experiment with train timetables during disruptive events.

Keywords: timetable, optimization model, data mining, high speed rail

INTRODUCTION
Nowadays, railway transportation has become a good alternative in many countries as an efficient and economic public transportation mode. It plays an important role in the passenger and freight transportation market. The railway has grown by over 40% in both freight and passenger sectors over the past 10 years1. All railway companies try to provide good services in order to satisfy their customers. One way to realize this is by improving the quality of the train control process or scheduling so that the railway company could optimize these services as well. In addition, the train timetable is the basis for performing the train operations. It contains information regarding the topology of the railway, train number and classification, arrival and departure times of trains at each station, arrival and departure paths, etc. More formally, the train scheduling problem is to find an optimal train timetable, subject to a number of operational and safety requirements. Scheduling problem in this research was emphasized to High-speed rail (HSR) system; a type of passenger rail transport that operates significantly faster than the normal speed of rail traffic. Specific definitions by the European Union include 200 km/h (120 mph) for upgraded track and 250 km/h (160 mph) or faster for new track. Commonly, HSR system has different system with normal speed railway due to the safety issues. It uses lines without branches and minimizes the amount of stoppage time to keep the speed constant. Managing circulation of trains during disturbances, including regular inspection, car cleaning times and turning back operations, has become important as the mitigation effort for minimizing consequences especially for high-speed system; which is known as a type of passenger rail transport that operates significantly faster than the normal speed of rail traffic and sensitive to disturbances. The Taiwan High Speed Rail (THSR) system already has cyclic patterns of daily train circulation, but these patterns have not been modeled yet especially during disturbances. Moreover, based on a review of the literature, only few researchers in the railway field have considered train circulation model, especially in high-speed rail systems, even though it is an important requirement and the arrangement of circulation time in a given timetable could be such a way that the timetable becomes maximally robust against stochastic disturbances2. The second issue is that railway systems are often characterized by high traffic density and heterogeneous traffic that is sensitive to disturbances, especially in high-speed railway system; thus, rescheduling activity for updating an existing production schedule in response to disruptions or other changes is needed3. The general problem is to decide when the trains get access to the tracks as well as if and
where the trains should meet and overtake while ensuring that safety restrictions and other considerations are maintained. In normal speed railway systems, this rescheduling could be done manually by the traffic management. It monitors the network and traffic status via a screen and has a pencil and a paper-version of the time–distance diagram of the timetable to adjust in line with the re-scheduling plans. However, in high-speed systems, as the name high-speed, predicting disturbance propagation and minimizing the consequences is a challenging problem because of the speed itself.

The benefits and challenges of the train scheduling method can contribute to improve the quality of the train control process. Thus, the optimization model that represents the real problem needs to be designed to support the train operator’s creation of an optimal schedule in limited computation times. Moreover, predicting the impact of disturbances on the timetable also needs to be addressed in order to anticipate and mitigate the worst condition. Those two problems are being faced by the THSR Company today; therefore, the objective of this research is to solve them by doing three tasks as follows: 1) designing an optimal timetable using an optimization-based approach which capability to accommodate basic requirements (railway topology, traffic rules, user requirements) and train circulation requirements (turning back, regular inspection and car cleaning times); 2) checking the model using real data from THSR Company; and 3) analyzing the responses of model results to the disturbances using sensitivity analysis.

The real problem in the THSR system is its use of a contingency timetable to solve the timetabling problem under disturbances. It considers two conditions of disruption effects: (1) low-speed running operation at a certain location, and (2) line track or station blocked. To solve the first condition, THSR creates a timetable with speed restrictions and applies it to the train running time and headway calculations. Each speed would create different timetable results. Moreover, to solve the second problem (line track blocked), the THSR Company uses five types of blocked track possibilities and one type of bi-directional solution. This system generates the timetable according to a specified train running route. Each condition also has different timetable results.

Nevertheless, as many contingency timetables can be prepared as planners can make in the THSR system. In fact, it still has a big problem, in that it is especially time consuming to maintain and select the appropriate contingency timetable for one disruption and create an optimal timetable during the disturbances. There are five thousand types of contingency timetables in the THSR Company, and the train operator should select the appropriate timetable within a limited time.

Furthermore, based on the data in the contingency timetable, THSR prefers to cancel many trains and operates only two trains per hour in many cases of disturbances. On the other hand, creating an optimal timetable, which means optimal journey time, is important since the THSR Company has to preserve the maximal profit during disturbances. In addition, in order to mitigate the impact of disturbances instead of cancelling many trains on their system, THSR needs a method for analyzing how disturbances propagate within the original timetable and which actions to decide to minimize the consequences. In the end, the train operator could predict the effects of disruptions on the timetable without doing real experiments.

**RELATED WORKS**

Train scheduling problems have been studied by researchers over the years. They have been formulated using operation research (OR)-based techniques including mixed integer programming and network optimization models. Among the solution techniques developed to solve the problems were branch and bound, heuristics, and lagrangian relaxation. In addition, researchers have proposed some methods to solve scheduling problems as the Job-Shop problem, program evaluation and review technique or PERT, and satisfaction constraint. The strengths and weaknesses of each method depend on research objectives. Many researchers prefer to use a heuristic method to speed up the computation time and direct the search towards a feasible solution, but a heuristic needs more evaluation in practice due to the optimality issue of the results. There is no guarantee that the heuristic will generate an optimal solution in every test case. The scheduling and rescheduling problem in this research is formulated as mixed-integer-programming (MIP), in which some of the variables are real-valued and some are integer-valued. There are two ways to solve MIP: exact solution, including branch and bound, and dynamic programming and approximation, including heuristic and lagrangian relaxation techniques. The most widely used method for solving MIP for exact solution is branch and bound, and no researchers have used dynamic programming as a solution technique, although it could obtain the optimal solution as well. Therefore, this research proposes the exact-solution algorithm, which is dynamic programming, to solve train-scheduling problems and get the optimal solution exactly.

Since the train-scheduling problem is being used to find an optimal train timetable, it has many rules to consider. Early work by Chiu has considered six types of scheduling rules in railway systems: speed constraints, station occupancy, station entry and exit constraints, stopover, and line time constraints. In

406
addition, railway topology, traffic rules, and user requirements have been considered in mathematical formulations modeled6. This research has contributed several additional constraints that arise in real-world timetabling applications. In particular, they address the following constraints: automatic and manual signaling, station capacities, maintenance operations, and periodic trains. However, based on the literature review, only few researchers in the railway field have never considered train circulation, especially in high-speed rail systems, even though it is an important requirement. Therefore, a scheduling model which has the capability to accommodate not only basic requirements (railway topology, traffic rules, and user requirements) but also train circulation requirements needs to be formulated.

In this paper, we use an optimization method to solve the train-timetabling problem similar to the one presented before6, but more complex, and discuss the problem of sensitivity analysis. Sensitivity analysis has been used in train timetabling fields, e.g., sensitivities of station spacing and sidings, showing its importance for a single-track line, or the influences of train speed on the performance of the line8. Castillo et al. have also analyzed sensitivity analysis in timetabling optimization of single-railway track line problems8. They applied sensitivity to add quality for solving methods, and it should be a routine complement to any optimization problem. Based on the results of sensitivity analysis, Castillo et al. concluded a corresponding among the number of stations, speeds, and total travel-times. Reducing the number of station would enhance speeds and travel-time among stations, thus total travel-time in line would reduce automatically. In the other hand, enhancing the number of station (intermediate) improves the performance of the line substantially, even though the dwell-time at station is considered. This research also used sensitivity to investigate the maximum relative travel-times with respect to dwell-times. The results concluded that only some trains modify the optimal solution locally if the dwell-times of those trains are modified. Otherwise, no such local affect, that is, a small change in the corresponding dwell times does not modify the optimal relative travel time.

In short, the sensitivity analysis provides important information about critical resources and trains, which used to improve the line and, indirectly, the timetable design. For example, in many important decisions, such as the number of stations, speed restrictions, departure times and dwell-times modifies, could be derived from the sensitivity analysis results.

**PROBLEM DESCRIPTIONS**

The proposed HSR system is about a 335.2 km intercity service line without branches along the western corridor of Taiwan. Railway topology of the THSR system consists of two connecting lines between southbound and northbound. It connects two major cities, Taipei and Kaoshiong with eight stations along the line as illustrated in figure 1. Each station has multi-tracks (at least two tracks) which are used as platforms, waiting time terminals, and free passes. In one day, the THSR Company provides 120 services with 29 trains running.

After knowing the THSR topology, we should understand the timetable components and rules in order to develop a robust mathematical model for the scheduling problem. A timetable contains information regarding railway topology (stations, tracks, distance among stations, traffic control, etc), and the schedules of the trains that use this topology (arrival and departure times of each train at stations, dwell-times, crossing times, car cleaning times, regular inspection times, and turning back operation). The timetabling design in this research is described as follows. Given the THSR railroad system and set of services, then the problem performs a timetable as well as a track assignment plan for these services.

The goals of the optimization model in this research are to let the trains depart as close to their target departure times as possible, at the same time minimizing the operation times of services. Since the operation times of each train as well as required headway between consecutive trains depend on the track assignment, railway topology and train circulation issues have to be considered simultaneously to obtain a realistic result which is close to the real timetable.

Therefore, the objective function in designing the timetable in this research is to minimize the total operation time for all train services subject to basic requirements (railway topology, traffic control, user requirements) and train circulation requirements (regular inspection, car cleaning, and turning back operation).

**MODEL DEVELOPMENT**

A model was developed to analyze a particular problem and may represent the different parts of the system. The scheduling model in this research was developed based on the real problem in THSR system and also from some assumptions below:

- **Optimal timetable in high-speed railway system** means that the timetable could perform the effective journey time to the passenger. Therefore, the objective functions for scheduling model in this research is to minimize the total journey time for all trains in the system.

- **The scheduling problem occurs in double lines railway system with multi tracks at each station.** The different topology of railway will create different formulation of model.
The upper bound (UB) value of this model is formulated as maximum operation speed of THSR (300 km/hour) or 186 mph. Since the distance between Taipei to Zuoying is 335.2 km, it takes 67 minutes travel and 15 minutes as the start point time to rich optimal speed of THSR. Therefore, the reasonable UB for this HSR line is 82 minutes. Under disturbances, this value of UB would be increase, since the speed decrease.

- Train circulation includes car cleaning activity, regular inspection, and turning back operation. Only Taipei and Zuoying provides train circulation activities, because these two stations have multi tracks that are possible to perform it.

The proposed mathematical model

Suppose a railway system with r station, n trains going down and m trains going up. Minimizing the operation times for all trains means minimizing the journey times (arrival and departure times) for all trains going-down, initialized as i (1 to n) plus the journey time of trains going-up as j (1 to m) in every station (1 to r). Thus, the mathematical constraint for representing the objective function in this research is presented as Equation (1) below to minimize total operation time:

\[
Z = \sum_{i=1}^{n}(T_i - T_{i+1}) + \sum_{j=1}^{m}(T_j - T_{j+1}) \\
\forall i=1-n \text{ and } \forall j=1-m
\]

(1)

The variables of this research are journey time, arrival and departure time of all trains with travel time, station time, headway, car cleaning time, regular inspection time and turning back operation, as parameters. Variables and parameters will be explained as constraints below:

- Travel time between two contiguous stations’ constraints

Travel time constraints restrict minimum time to travel between two contiguous stations (k to k+1) for all trains going up initialized as i (1 to n) and trains going down initialized as j (1 to m).

\[
T_{i+1}, T_{i} \geq \text{time } i_{(k+1)-i} \forall i = 1-n \text{ and } \forall k = 1-r
\]

(2)

As represented by Equation (2), the arrival time for train i in the same station k minus departure time in the station k (origin station) should be greater or equal to the needed time for trains i to travel between two contiguous stations (k to k+1).

\[
T_{i} - T_{i+1} \geq \text{time } j_{(k+1)-i} \forall j = 1-m \text{ and } \forall k = 1-r
\]

(3)

The arrival time for train j in the station k minus departure time in station k+1 should be greater or equal to the needed time for trains j to travel between two contiguous stations (k+1 to k). This research uses minimum travel time between two contiguous stations, because different types of trains have different speeds and travel time would automatically differ.

- Dwell time constraints

As explained before, running time is calculated from departure times in the timetable minus dwell times. Therefore, station time for each train i and j at station k (1 to r) should be greater than departure time minus arrival time, as shown in Equations (4) and (5). This condition represents that the model uses maximum station time at each station, because not all trains will stop at every station.

\[
T_i - T_j \leq \text{TS}_{i} + \text{CS}_{i} \forall i = 1-n \text{ and } \forall k = 1-r
\]

(4)

\[
T_i - T_j \leq \text{TS}_{j} + \text{CS}_{j} \forall j = 1-m \text{ and } \forall k = 1-r
\]

(5)

- Headway constraint

Headway constraint restricts to the departure times differences between two consecutive trains in the same station. The headway time in this research is fixed to one value because we want to keep the time spacing between two trains exactly.

\[
T_i - T_j = \text{headway} \forall i = 1-n \text{ and } \forall k = 1-r
\]

(6)

\[
T_i - T_j = \text{headway} \forall j = 1-m \text{ and } \forall k = 1-r
\]

(7)

- Travel time in line constraints

Travel time in line determines the total travel time for one train to travel through a line southbound and northbound plus allowed time margin. Maximum travel time has been applied in the model; thus, the difference between arrival and departure time for one train in the same station should be less or equal to this travel time, as formulated in Equations (8) and (9) below:

\[
T_i - T_j \leq [(1 + \frac{\eta}{100}) \times \text{time } i_{\text{line}}]
\]

(8)

\[
T_i - T_j \leq [(1 + \frac{\eta}{100}) \times \text{time } j_{\text{line}}]
\]

(9)

In the THSR system, allowed time margin was set to different numbers for different types of train. Therefore, this parameter would be a good input in sensitivity analysis to reveal the effects of changes in this parameter on objective value.

- Crossing time constraints

Although the THSR system has multiple tracks at stations, sometimes crossing operations become necessary for one train to allow another train to pass through the station. In this constraint, it is assumed that crossing time would be performed by two trains headed in different directions (southbound and northbound trains). Thus, the difference between arrival time for train i and departure time for train j at the same station k+1 (because the second train had already departed from its original station) should be less or equal to the upper bound time minus buffer time in the available segment. is the decision variable for the availability of track in one segment. The value is 1 if there is a track available between station k to k+1 and 0 otherwise, as formulated in Equation (10) below:

\[
T_i - T_j \leq UB \times (1 - Y_{r, i_{(k+1)-i}}) \forall i = 1-n \text{ and } \forall j = 1-m
\]

(10)

- Train circulation constraints
Like many railway companies, THSR has a cyclic timetable in order to manage the resources comprising its infrastructure. In this research, it is assumed that the cycle time is 120 minutes (maximum travel time). Thus, if the headway time is set to 12 minutes, it means there are ten trains in the first cycle, and the next train (11th train) would be the same train as number one. It means the timetable at every two hours is the same pattern; the daily timetable is obtained by carrying out this pattern repeatedly. A train circulation model is needed to deal with these requirements. In the THSR system, train circulation takes 30 minutes maximum time, including car cleaning, regular car inspection, and turning back operations. Consequently, departure time for another train which will use the same track as those operations should be greater or equal to arrival time plus train circulation times as formulated in Equations (11) and (12) below:

\[
T_{\text{max headway}} \geq T, A_i + (\text{Ins}_T + \text{CIT}_T + \text{TB}_i)
\]  

(11)

\[
T_{\text{max headway}} \geq T, A_j + (\text{Ins}_T + \text{CIT}_T + \text{TB}_i)
\]  

(12)

If there were an event that required long travel times and headway between two contiguous trains, then the train circulation pattern would change as well.

Data collection

After the mathematical model for scheduling problem was formulated, a collection of data regarding scheduling requirements from the THSR Company began. Data requirements list are number of stations, number of trains in southbound and northbound line, headway time, allowed margin time, upper bound in line, station time, distance between stations, and the operation time regarding train circulation. Primary data was collected from interviews with senior engineers in the THSR Company, and secondary data was gathered from THSR documents including the Equipment and Facilities Operations Manual, and existing timetables from THSR. To accommodate data modification during model development process, a scheduling database has been built using Microsoft Office Access Database. This databases consists of stations ID, trains ID, train directions ID, train sequences ID, model parameters ID, and the table value for all parameters.

Sensitivity analysis

Figure 1 shows the results of the THSR timetables using the proposed model. Figure 2 is the result of delay event for each train 9 minutes in High Speed Rail system, and it can be bring that the effect for train timetable delay. In this figure, the train ID’s are the 10(time for morning), 30(time for noon) and 50(time for afternoon) for south bound train respect
TAICHUNG, CHIAYI, TAINAN and ZUOYING. If a train is stop delay at some station, the other stations are also delay. Therefore, the train is delay near at first station, it can be effected the timetable delay time many more. For example, the south bound train ID is 50 for stop-all-station, which stop 1 minute at time many more. For example, the south bound train first station, it can be effected the timetable delay are also delay. Therefore, the train is delay near at train is stop delay at some station, the other stations TAICHUNG, CHIAYI, TAINAN and ZUOYING. If a Fig.4. Effective trains at the middle station.

delay about 30 minutes.
effect large of effective train number is by train stop at the back. In this figure that can explain that creasing), that is the delay time is so long for effect number of effective train is not increasing (it's de-
creasing also. But for delay time is 63 minutes, the number of effective train is not increasing (it’s de-
creasing), that is the delay time is so long for effect train at the back. In this figure that can explain that
effect large of effective train number is by train stop delay about 30 minutes.

CONCLUSIONS
This research developed an optimization model for designing timetables in high-speed railway systems that consider basic requirements as well as special requirements regarding train circulation, including car cleaning, regular inspection, and train turning back operations. The model could generate a good timetable result as good as a real timetable in a short computation time (0.10 seconds). Furthermore, the model could generate train circulation patterns as illustrated in the timetable diagram results.

References
Is color an intrinsic property of construction object’s representation? Evaluating color-based models to detect objects by using data mining techniques

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Purpose Structural component detection is a prerequisite for various applications, including construction progress measurement and quality inspection. However, it is still a challenge to detect structural components reliably in construction site images taken from a complex and unstructured construction environment. Because construction site images contain numerous unexpected objects, structural components in the images are observed under different poses and varying lighting conditions. The aim of this study is to discover how color information effectively works on structural component detection in construction site images by incorporating hybrid data mining techniques.

Method To verify the effectiveness of the color-based models for structural components detection, this study involves data collection, feature selection, and color-based model building. First, this study tried to collect the most comprehensive data set on structural components detection before assessment. Second, it attempted to extract the best set of effective color features among all the available color features through feature selection. Third, this study evaluated and compared the performance of the constructed color-based models (defined in terms of accuracy rate) using hybrid data mining techniques. This study then identified the most effective configuration of color features and data mining techniques to detect structural components.

Results & Discussion The experimental results suggest that color can be a powerful cue for reliable detection of structural components in construction site images. The use of the set of color features in combination with a hybrid data mining technique in structural component detection is highly accurate (accuracy rate above 95%) in detecting structural components composed of major construction materials (e.g., concrete, steel, and wood). The results from structural components detection that are obtained by the proposed combination are reliable for use as an essential input for various applications, including construction progress measurement and quality inspection.

Keywords: automation, color, construction object detection, data mining technique, ensemble model

INTRODUCTION
The automatic detection of objects in photographs acquired from construction sites is essential for a wide range of applications, including but not limited to, materials tracking, automated control of heavy equipment, progress monitoring, quality control, and the generation of 3D as-built models. As the first step of processing construction photographs, successful and efficient object detection is critical to the success of these applications and greatly affects the subsequent steps. However, it is challenging to automatically detect objects in construction photographs due to the possible appearance and shape variations of the objects. Unlike a well-structured manufacturing environment, a construction site contains objects of unpredictable shape and position due to the uncertain and unstructured nature of the environment. Moreover, a construction photograph contains a variety of objects that are cluttered, intertwined, occluded, and articulated. This complexity, which is inherent to most construction sites, makes the automatic detection of particular objects non-trivial and difficult. To handle the problem of object detection in such an unstructured and complex environment, an object detection approach based on the colors of the objects has been proposed as an effective way to distinguish an object of interest from the other objects in its vicinity. The color-based object detection approach has obvious and powerful advantages, especially in unstructured and complex environments, because it is independent on the appearance, shape, and position of the objects. In addition, this approach is simple and computationally efficient to implement because it only requires the color values of each pixel in construction photographs. By taking advantage of this approach, color-based object detection has been successfully validated for use in a number of areas (e.g., detection of skin, roads, traffic signs, and so forth). The results of previous studies indicate that color is a useful and robust feature for object detection. This approach seems to be useful for detection of particular objects in construction photographs. Despite the fact that automatic detection of objects in construction photographs has been explored in
some recent studies within the construction industry, whether the color of an object is actually useful in the automatic detection of that object in such photographs has not been investigated. In addition, a method to test the usefulness of the color of an object in its detection is rarely considered. Consensus about whether the color of an object is genuinely useful in the detection of that object in construction paragraphs has not been reached among researchers in the construction industry. Most researchers are concerned about the perceived difficulty of detecting particular objects in construction photographs using only their inherent color properties, particularly when the color of the object of interest is similar to the others around it or even when the inherent color property of the object of interest is altered due to the effect of varying illumination that occurs in outdoor environments. Based on these concerns, researchers have regarded the detection of specific objects in construction photographs solely by colors as insufficient and difficult. Hence, there have been several attempts to detect particular objects in construction photographs using the color of an object together with its shape or with its texture. However, the methods proposed by these researchers suffer from limitations resulting from a lack of consideration of the variations in object surface properties such as texture, changes in illumination, viewing direction, partial occlusion of the object of interest, and the presence of background objects.

The aim of this study is to clearly verify whether an object’s color information is useful for detecting that object in construction site photographs, with the questioning centering on manmade objects of concrete and steel and natural objects of wood. This paper collects a comprehensive data set for analysis and describes how we can consider the effects of varying illumination in an outdoor environment to take full advantage of color for object detection. Then, the usefulness of color information for detecting an object is verified through incorporating data mining techniques as the main focus of an investigation. The paper is organized as follows: in the next section, the data set used in the study is described. Section 3 briefly characterizes the eight data mining techniques selected for the study. Section 4 presents experimental results, and the last section concludes with a discussion.

**Materials**

**Data Set**

Without a comprehensive data set, it is meaningless to declare the detection of a color-based object “useful” or “not useful,” let alone quantify its utility. Since the comprehensive data sets for construction object detection are not readily available in the construction industry, a total of three data sets for concrete, steel, and wood detection, respectively, were generated. The appearance of a construction object’s surface colors can be affected by environmental factors such as changes in the direction and intensity of illumination. Because most construction sites are outdoors, illumination intensity varies unpredictably and uncontrollably, depending on the time of day, seasonal variations, and weather conditions (sunny, cloudy, or foggy), thereby resulting in large variations in the appearance of a construction object’s surface colors.

To cover such variations, 108 photographs were taken at a total of 50 construction sites for concrete detection, 91 photographs were taken at a total of 80 construction sites for steel detection, and 50 photographs were taken at a total of 14 construction sites for wood detection.

Each photograph was then divided into 25 × 25 or 50 × 50 pixel subregions. The subregions were categorized and labeled as an object of interest, background, or indeterminate. The subregions categorized as indeterminate were excluded from the dataset. As a result, each component of the data set is composed of object and non-object pixels. The former refers to pixels related to objects such as concrete, steel, and wood, while the latter refers to pixels related to background. In order to verify whether only the color of objects made of concrete, steel, and wood is sufficient for distinguishing these objects from others, this study made a particular effort to collect and include as many objects as possible with similar color properties as the objects of interest. The background objects include all kinds of scenery—bricks, construction equipment, fences, forms, pipes, safety nets, the sky, soil, traffic signs, trees, windows, and other construction-related materials.

In total, the data collected from the concrete, steel, and wood subregions and their background subregions amounted to over 113 million pixels, 95 million pixels, and 35 million pixels, respectively, for concrete, steel, and wood detection. The first concrete data set contains approximately 44 million pixels from the concrete and approximately 69 million pixels from the background pixels. The second steel data set consists of 9 million pixels from the steel and approximately 85 million pixels from the background. The third wood data set has 10 million pixels from the wood and approximately 25 million pixels from the background. The characteristics of the three data sets are provided in Table 1. In summary, the data sets were well balanced in terms of time of day, season, and weather. The percentages of data collected during a.m. and p.m. hours and PM hours were roughly comparable. There was greater variation in the percentages of data collected in different seasons, as well as in the percentages of data collected under different weather conditions, as shown in Table 1.
HI)). Hue and saturation ($H$ and $S$), and intensity ($I$). Hue and saturation are related to color, or chromaticity, and the illumination-independent components. The HSI colorspace is defined as:

$$H = \arctan \left( \frac{\sqrt{3}(G - B)}{(R - G) + (R - B)} \right)$$

$$S = 1 - \frac{\min(R, G, B)}{I}$$

$$I = \frac{(R + G + B)}{3}$$

**METHODS**

**Classification Models**

Seven classification models and an ensemble model were applied and compared: 1) artificial neural networks (ANN), 2) support vector machines (SVM), 3) classification and regression tree (CART), 4) quick unbiased efficient statistical tree (QUEST), 5) commercial version 5.0 (C5.0), 6) exhaustive chi-squared automatic interaction detector (CHAID), 7) logistic regression (LR), and 8) ensemble model. The first two models are derived from machine learning techniques, the latter four models from classification and regression-based techniques, and the seventh model from multivariate statistical techniques.

Artificial Neural Networks (ANN)

In this study, a back-propagation (BP) neural network is used for classification. This is a feed forward network that can have 1 or more hidden layers. It utilizes an iterative gradient search technique designed to minimize the mean square error between the actual and desired net outputs. The units in the hidden layer sum their inputs, add a constant, and take a fixed function of the result. The output units are of the same form, but with output function. A three-layer network with 1 hidden layer was proven to be capable of computing any continuous likelihood function required in a classifier and solving complex binary classification problems. The logistic function was selected as the activation function in this study.

Support Vector Machine (SVM)

The SVM, inspired by a statistical learning theory, is one of the most powerful machine learning techniques for solving a large number of complex binary classification problems. It acts as a linear classifier in a high dimensional feature space transformed through a projection from the original input feature space by taking non-linear functions (kernel) of the original data set. Hence, in general, the resulting classifier is non-linear in the input space. The SVM achieves good generalization performances by finding a hyperplane that maximizes the margin between the classes. The radial basis function (RBF) was selected as the kernel function in this study. For further details, see Vapnik and Vladimir and Vapnik.

Classification and Regression Tree (CART)

CART is one of the decision tree algorithms that induces a binary tree on a given set of training data, resulting in a set of “if-then” rules. These rules can then be used to solve classification or regression problems. CART is a robust, easy-to-use decision tree tool that automatically sifts large, complex databases, searching for and isolating significant patterns and relationships. It uses a recursive partitioning, a combination of exhaustive searches and intensive testing techniques, to identify useful tree structures in the data. The knowledge thus discovered is used to generate a decision tree, resulting in reliable, easy-to-grasp predictive models. It constructs the decision tree by splitting subsets of the data set using all predictor variables to create two child nodes repeatedly, beginning with the entire data set. The best predictor is chosen using a variety of impurity or diversity measures. The goal is to produce subsets of the data that are as homogeneous as possible with respect to the target variable.

<table>
<thead>
<tr>
<th>Category</th>
<th>Data Set</th>
<th>Concrete (%)</th>
<th>Steel (%)</th>
<th>Wood (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.m.</td>
<td>56.9</td>
<td>33.0</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>p.m.</td>
<td>43.1</td>
<td>67.0</td>
<td>70.0</td>
<td></td>
</tr>
<tr>
<td>Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>23.2</td>
<td>9.9</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>16.7</td>
<td>16.5</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>46.8</td>
<td>32.9</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>13.2</td>
<td>40.7</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloudy</td>
<td>13.1</td>
<td>18.7</td>
<td>44.0</td>
<td></td>
</tr>
<tr>
<td>Foggy</td>
<td>11.5</td>
<td>8.8</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Sunny</td>
<td>75.4</td>
<td>72.5</td>
<td>52.0</td>
<td></td>
</tr>
</tbody>
</table>

**Data Representation**

Another issue that must be carefully considered to take full advantage of color-based object detection is how to effectively reduce the effect of varying illumination on object color changes that occur in outdoor environments. The values of colors in the RGB (red, green, and blue) colorspace, the most prevalent choice for computer graphics, are particularly subject to deterioration as a result of changes in illumination. Such variations caused by factors in outdoor environments may dramatically affect color properties, potentially impacting detection performance. To deal with this potential artifact, it is important to new-

Table 1. Distribution of data collection by time of day, season, and weather
Quick Unbiased Efficient Statistical Tree (QUEST)  
QUEST is a binary-split decision tree algorithm for classification problem. It can be used with univariate or linear combination splits. One of its features is that its method for attribute selection has negligible bias. If all attributes are uninformative with respect to the class attribute, then each attribute has approximately the same chance of being selected to split a node.  

Commercial Version 5.0 (C5.0)  
The supervised learning algorithm (C5.0) is used to generate the set of rules from the data. As such, it employs a divide-and-conquer approach, rather than a separate-and-conquer one. After inducing the trees, a post-processing step produces the rules. It uses a pruning strategy by which a branch is pruned when the error is one standard error of the existing errors adjusted for the correction of continuity.  

Exhaustive Chi-Squared Automatic Interaction Detector (CHAID)  
The CHAID is based on the chi-square test of association. It constructs a decision tree by repeatedly splitting subsets of the space into two or more child nodes, beginning with the entire data set. In order to determine the best split at any node, any pair of categories of the predictor variables is merged until there is no statistically significant difference within the pair with respect to the target variable. It naturally deals with interactions between the independent variables that are directly available from an examination of the tree. The final nodes identify subgroups defined by different sets of independent variables.  

Logistic Regression (LR)  
Logistic regression is a model for binomially distributed dependent variables. It is a generalized linear model that uses the logit as its link function. Binomial (or binary) logistic regression is used when the dependent variable has a dichotomy and the independent variables are of any type. Logistic regression applies a maximum estimation of likelihood after transforming the dependent into a logit variable (the natural log of the odds of the dependent occurring). In this way, logistic regression estimates the probability of occurrence of a certain event. Using logistic regression has advantages over linear discriminant analysis, including coefficients interpretable (odds-ratios), standard errors calculable (but only asymptotic), and maximum likelihood instead of least squares, but at the risk of non-convergence of the algorithm.  

Ensemble Model  
This study also takes into account the ensemble model to evaluate the performance of the color-based models with regard to construction object detection. An ensemble model involves training multiple single classifiers (so-called member classifiers) and subsequently combining them to form a single classification model. Hence, the classification performance of an ensemble model strongly depends on the performance of the base classification models. Ranking the performance of the above seven classification models enables selection of the best performing models, which can be combined into a single ensemble model. This approach often yields more accurate classification results compared to a single classification model because it aggregates the benefits of multiple models. The ensemble model combined in this manner generally performs at least as well as the best individual models, and often better. In this study, the three best-performing single models were combined to produce an ensemble model. As a way of combining different single models' classification results to obtain the overall classification result, the highest confidence wins was selected in this study.  

Model Validation Methods  
For evaluation of each of these eight classification models' classification performance, k-fold cross validation was used. This method is known for its tendency to minimize bias and variance among all validation methods, including the leave-one-out method. Extensive studies on numerous data sets with different classification models have demonstrated that 10 folds are optimal in terms of computation and estimation of error, and there is theoretical evidence backing this up. Thus, a 10-fold cross validation approach was used to assess the performance of eight classification models. In each 10-fold cross validation, the data was split into 10 approximately equal folds, with each in turn being used for testing and the remainder being used for training. That is, 9 of the 10 folds are used for training and the kth holds out folds for testing, and repeats the procedure for k = 1, 2, ..., 10, so that by the end, every instance has been used exactly once for testing. The cross validation estimate of overall performance is then calculated by simply averaging the 10 individual performance evaluation measures for 10-fold cross validation performance.  

Performance Evaluation Measures  
Various approaches have been suggested for evaluating the performance of classification models. To determine whether a method of color-based object detection is “useful” or “not useful,” a partial measure of the performance is inadequate, because evaluation on performance measures needs to be comprehensive. For this reason, performance evaluation measures employed in this investigation consist of six measures: accuracy, precision, sensitivity, specificity, area under the receiver operating characteristics curve (AUC), and overall
average performance score (S). The first five measures are extensively used to evaluate the performance of the classification models.\textsuperscript{25, 26, 27} They can be calculated by computing the number of correctly predicted pixels of the object of interest (true positives, $TP$), the number of correctly predicted pixels that belong to the background objects (true negatives, $TN$), the number of pixels that were incorrectly assigned to the object of interest (false positives, $FP$), and the number of pixels of the object of interest that were incorrectly assigned to the background objects (false negatives, $FN$).\textsuperscript{28} The last measure is derived to evaluate the overall performance of the classification models by compounding the effect of the first five measures. It is calculated by averaging the values of the first five measures, with the value of $S$ being positively related to the effectiveness of the overall evaluation measures. The first five measures are determined by the following equations:

\[
\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}
\]

\[
\text{Precision} = \frac{TP}{TP + FP}
\]

\[
\text{Sensitivity} = \frac{TP}{TP + FN}
\]

\[
\text{Specificity} = \frac{TN}{FP + TN}
\]

\[
AUC = \frac{1}{2} \left( \frac{TP}{TP + FN} + \frac{TN}{FP + TN} \right)
\]

**EXPERIMENTAL RESULTS AND DISCUSSION**

For the color of an object to be a useful feature in its detection, it should be verified that the color of the object alone is sufficient for distinguishing it from others. Table 2 lists the statistical results regarding the effectiveness and usefulness of color for the detection of concrete, steel, and wood. The results are generated using 10-fold cross validation by seven single classification models and one ensemble model for three data sets for concrete, steel, and wood detection, respectively.

Regardless of the type of classification model, the results imply that concrete, steel, and wood detection can be achieved using color information alone, ranging from 90.40% to 96.24% in accuracy, 95.66% to 98.16% in precision, 83.86% to 94.24% in sensitivity, 96.08% to 98.27% in specificity, and 90.40% to 96.24% in AUC. These results strongly indicate that color information is very effective and useful in construction object detection for objects made of concrete, steel, and wood. To further demonstrate the classification capabilities of different classification models, this study investigated and compared the effectiveness of seven single classification models and an ensemble model in concrete, steel, and wood detection, respectively. The ensemble model demonstrated the best performance for all three data sets in accuracy, precision, sensitivity, specificity, AUC, and $S$, except for precision in wood data set and specificity in concrete, steel, and wood data sets (see Table 2). SVM followed the ensemble model. Table 2 draws the following conclusions about the performance of the ensemble model. On the one hand, although the differences in performance be-

### Table 2. Classification performance for each data set

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Methods</th>
<th>Accuracy (%)</th>
<th>Precision (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>AUC (%)</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>ANN</td>
<td>90.20</td>
<td>93.48</td>
<td>86.45</td>
<td>93.94</td>
<td>90.20</td>
<td>90.85</td>
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<td>92.24</td>
<td>95.58</td>
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<td></td>
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<td>CHAID</td>
<td>89.44</td>
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<td>89.50</td>
<td>91.12</td>
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<td>91.47</td>
<td>89.50</td>
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<td>95.93</td>
<td>92.79</td>
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<td>Steel</td>
<td>ANN</td>
<td>94.03</td>
<td>97.64</td>
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<td></td>
<td>SVM</td>
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<td>98.15</td>
<td>94.54</td>
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</tr>
<tr>
<td></td>
<td>CART</td>
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<td>85.93</td>
<td>81.04</td>
<td>86.73</td>
<td>83.88</td>
<td>84.29</td>
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<tr>
<td></td>
<td>Ensemble</td>
<td>96.24</td>
<td>98.16</td>
<td>94.24</td>
<td>98.24</td>
<td>96.24</td>
<td>96.62</td>
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<tr>
<td>Wood</td>
<td>ANN</td>
<td>89.26</td>
<td>95.69</td>
<td>82.29</td>
<td>96.29</td>
<td>89.26</td>
<td>90.55</td>
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<td>82.15</td>
<td>97.13</td>
<td>89.64</td>
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<td>CART</td>
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<td>88.67</td>
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<td>96.49</td>
<td>83.86</td>
<td>96.95</td>
<td>90.40</td>
<td>91.62</td>
</tr>
</tbody>
</table>
between the ensemble models and single classification models are not large, the ensemble models for all three data sets generate more successful results than single classification models do. It can be seen that the performances of the ensemble models are better than any other based single classification models, especially the accuracy, sensitivity, and AUC values, which increase slightly. The comparison results confirm that the ensemble model can effectively deal with construction object detection using color information alone and improve classification performance better than single classification models.

CONCLUSIONS

In this study, we attempted to discover whether color information of various objects alone is useful for their detection in photographs acquired from construction sites. For this reason, the effectiveness and usefulness of the color information in construction object detection, such as concrete, steel, and wood, were evaluated using the seven single classification models and one ensemble model for collected comprehensive data sets. Relevant to this debate, our results can be interpreted as evidence for the idea that color is an intrinsic component of the representation of construction objects. This conclusion is based on the results obtained in comparison with single classification models. Color information in handling concrete, steel, and wood detection provides accuracy between 90.40% to 96.24%, precision between 95.66% to 98.16%, sensitivity between 83.86% to 94.24%, specificity between 96.08% to 98.27%, and AUC between 90.40% to 96.24%. Among eight classification models, the overall performance of the ensemble model that combines the three best performing single models was compared to seven single classification models, which were slightly better than those of the single classification models. In summary, the results clearly indicate that construction object detection in construction photographs using color information alone is quite effective. The results by the proposed method would be reliable for use as an essential source of input for various applications. These include, but are not limited to, materials tracking, automated control of heavy equipment, progress monitoring, quality control, and the generation of 3D as-built models. For future work, the evaluation will be expanded to explore the ability of the color information with regard to a number of types of construction objects, including curtain walls and masonry, leading to a practical implementation. In addition, we believe that further improvements are possible regarding the efficiency and performance of construction object detection using color information by investigating other ensemble models, such as bagging, boosting, and random forest.

ACKNOWLEDGEMENTS

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References


Combining automatically and manually collected data for project monitoring and control

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Purpose In an extended research program, started about two decades ago, a number of models have been developed for monitoring and controlling construction. These include models for the control of materials, earthmoving equipment, guardrail installation and labor. All these models convert data on the actual project performance that is obtained through Automated Data Collection (ADC) technologies, into information that can be compared with the project plan. Tests that were conducted with these models indicate that the use of ADC can substantially improve project control, but that in the areas that were studied manually obtained data is required as well, due to the limitations of existing ADC technologies, and due to the complexity and unpredictability of human actions. The proposed paper will discuss how manually and automatically collected data can be combined for project monitoring and control.

Method In addition to ADC, manual data is currently required to support project monitoring – i.e., the identification of deviations from the planned performance that will likely lead to significant problems in the project. For example, tests show that in order to obtain information on the actual duration of activities, a manual recording of their completion time is required in addition to the automated tracking of workers. This can be facilitated through the use of data taken from a computerized daily site report. These data are transformed by a progress monitoring model into information regarding the actual progress, and then transferred to scheduling software. Project control involves taking the measures necessary to correct or minimize significant deviations. However, it is often difficult to automatically identify the actual impact these measures might have on the project. To facilitate project control, a graph-based model that can be used to identify the project elements affected by proposed measures, is expanded to include data that is manually added by users. This data includes tacit knowledge regarding existing buffers in the project, and decisions by project team members on the way in which measures will be implemented.

Results & Discussion Different methods can be used for the integration of data from manual and automated sources. A model that uses the daily site report for project monitoring was implemented in a computerized prototype and tested in a construction project. Another model, that combines a graph-based representation of the project with manual data from project team members for project control, was tested in simulations with experts. The results of these tests were positive, and demonstrated the usefulness of the proposed approach.

Keywords: automation, project control, automated data collection

INTRODUCTION
A number of models for monitoring and controlling construction projects have been developed in an extended research program, called Automated Project Performance Control (APPC), which started about two decades ago. These include models for monitoring materials, earthmoving equipment, guardrail installation and labor. All these models use, as an input, data on the actual project performance that is obtained in real-time, through Automated Data Collection (ADC) technologies. The models convert this data into information regarding the project performance indicators (PPI) – such as cost, schedule, productivity, inputs consumption etc. These PPI can be compared with the project plan to identify deviations.

Research on the use of ADC technologies was motivated by the deficiencies of existing practices of collecting data through site inspections, extracting planning data from drawings, plans and databases, and comparing these through extensive calculations. All these actions are performed manually, and are therefore labour intensive, error prone and infrequent. A second major driver for the APPC program is the rapid technological developments in ADC technologies and their declining costs. Readily available technologies allow:

- Tracking workers, equipment and materials using Barcode, Radio Frequency Identification (RFID), Ultra-Wide Band (UWB) and Global Positioning System (GPS) technologies.
- Recording construction progress through video cameras, image processing systems and laser scanners.
- Continuous updates of an integrated computer-based project model.
Executing construction projects while adhering to the planned performance requires two main processes (Figure 1):

1. **Project monitoring** – the identification of those deviations from the planned performance, in the actual execution of the project, which are likely to lead to significant problems in the project.
2. **Project control** – taking the measures necessary to correct or minimize significant deviations.

**Project monitoring** involves: (a) a comparison of data that is collected on the construction site with the planning data; (b) an identification of any discrepancies between the two datasets; and (c) an analysis of the deviations to identify those that are indicators of significant problems in the project, and which therefore require controlling actions.

**Project control** involves: (a) the proposal of measures to solve the identified problems and reduce further deviations; (b) an analysis of the proposed measures to identify their impact on the project; (c) an approval of measures that are identified as having the desired impact; and (d) an update of the project plan according to the approved measures.

![Fig. 1. Project Monitoring and Control](image)

Tests that were conducted with the models that were developed in the APPC program demonstrate that ADC technologies can help overcome some of the current limitations of manual construction project monitoring. However, they also indicate that in the areas that were studied, some manually obtained data is still required in addition to the automatically collected data. One reason for this is the limitations of existing ADC technologies, which make it difficult to use them for all the aspects of monitoring construction projects. A second reason is the complexity and unpredictability of human actions, which accordingly require human knowledge and judgement to analyze and control them. Manual input is required both for the identification of significant deviations that have occurred, as well as for the identification of the measures that are suitable for controlling these deviations. In light of these findings, this paper discusses how manually and automatically collected data can be combined for both project monitoring and project control.

**Project Monitoring**

All the project monitoring models that were developed in the APPC program relied on ADC technologies for their input (Table 1). However, they also required some manually collected data (Table 2). Thus, a model for monitoring construction materials was successfully developed and implemented in an ongoing building construction project. The model can issue up-to-date reports on: the materials required for construction; materials that should be ordered; actual material flows (materials that arrive to the site, that are dispatched for use, and that remain in stock); and open purchase orders. Barcode or RFID were proposed as technologies for tracking the materials. However, these technologies cannot be used to track bulk materials, since barcode or RFID tags cannot be attached to such materials. Thus, bulk materials would still have to be manually tracked on the site. Damaged materials have to be manually identified as well.
### Table 1. Inputs of different models for monitoring construction projects

<table>
<thead>
<tr>
<th>Project monitoring area</th>
<th>Model input</th>
<th>From ADC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td>- Project schedule &lt;br&gt;- Planned inputs for activities &lt;br&gt;- Catalogues of construction materials</td>
<td>- Incoming materials  &lt;br&gt;- Materials dispatched for use (Potential technologies: Barcode or RFID)</td>
</tr>
<tr>
<td><strong>Earthmoving equipment</strong></td>
<td>- Physical design &lt;br&gt;- Project schedule &lt;br&gt;- Planned productivity</td>
<td>- Equipment location (Experiments conducted with GPS)</td>
</tr>
<tr>
<td><strong>Guardrail installation</strong></td>
<td>- Physical design &lt;br&gt;- Project schedule &lt;br&gt;- Relevant safety regulations</td>
<td>- Guardrail location (Potential technology: sensors on guardrail posts)</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>- Physical design &lt;br&gt;- Project schedule &lt;br&gt;- Planned labor inputs</td>
<td>- Worker location (Potential technology: RFID; Experiments conducted with video analysis)</td>
</tr>
</tbody>
</table>

### Table 2. Outputs of the models and additional required data

<table>
<thead>
<tr>
<th>Project monitoring area</th>
<th>Model output</th>
<th>Missing data required for monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td>- Required materials &lt;br&gt;- Materials to be ordered &lt;br&gt;- Material flows &lt;br&gt;- Open purchase orders</td>
<td>- Bulk material flows  &lt;br&gt;- Quality (e.g. damaged materials)</td>
</tr>
<tr>
<td><strong>Earthmoving equipment</strong></td>
<td>- Actual vs. planned productivity &lt;br&gt;- Actual vs. planned progress</td>
<td>- Quality Assurance Testing</td>
</tr>
<tr>
<td><strong>Guardrail installation</strong></td>
<td>- Dangerous areas &lt;br&gt;- Dangerous activities &lt;br&gt;- Scheduled guardrail installation &lt;br&gt;- Missing guardrails in current dangerous areas</td>
<td>- Project risk assessment</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>- Actual vs. planned labor inputs</td>
<td>- Time of completion of activities</td>
</tr>
</tbody>
</table>

Other models similarly required some manual input. A model for monitoring earthmoving equipment relied on GPS technology to track the location of the equipment\(^3,10\). The model uses algorithms to convert the data that was collected through GPS, and to identify deviations of the actual productivity and progress of activities from the project plan. However, certain manual quality assurance activities are still required to capture all the data. Data from sensors on guardrail posts was proposed as an input for another model, for planning and monitoring the installation of guardrails to prevent fall accidents \[^9\]. This model can issue reports on: dangerous areas and activities in the project; scheduled guardrail installation activities; and guardrails that are missing in currently dangerous areas. However, a manual risk assessment by the project management team is also required, based on general characteristics of the project such as the construction method, number of floors, height of a typical floor, and the type of construction (e.g., residential, commercial).

An additional labour monitoring model uses automatically collected data on the location of workers to identify and report deviations of actual labor inputs from the project plan\[^1,7\]. The model associates specific workers with certain planned activities, by identifying their location within the predefined work envelopes of these activities. These work envelopes are defined in relationship to the components for which the activities have been planned.

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421
Tests that were carried out with the labour monitoring model used video cameras to simulate an automated tracking of workers, in order to identify the duration of their presence within a work envelope. A model was then used to calculate the duration of activities based on this data. However, when these calculated durations were compared with the actual, manually recorded durations of the same activities, significant discrepancies of up to 115% were observed. A statistical analysis revealed that the relative size of these discrepancies varied in accordance with the duration of the activity, and the profession of the worker. Thus, the discrepancies for workers carrying out short formwork activities were relatively much larger than those for workers carrying out long concrete pouring activities.

The main reason for the discrepancies between the inputs that were identified with the labour monitoring model and the actual inputs, was the inability to automatically indentify, in real-time, the exact moment at which an activity had been concluded. Clearly, some manual recording of the conclusion of an activity can solve this problem. The question remains, how such manual data can be efficiently combined, within the same model, with the data obtained through ADC technologies. In order to achieve this, the manual data has to be recorded in a computerized database, which is integrated with the project planning database and the monitoring models.

The APPC program included an attempt to achieve such an integration, through the development of a model that uses data taken from a computerized daily site report (DSR) to generate monitoring and control information. The DSR holds a vast amount of detailed and up to date manually recorded data on the project, including on work that has been accomplished. Currently, this data is not normally used for the management and control of an ongoing project – it is used instead for litigation regarding claims and other disputes. The progress monitoring model that was developed uses data from a computerized version of the DSR, together with data that is extracted from the project planning database, to generate information regarding the actual progress in the project. This information is then transferred to scheduling software in order to update the project schedule, and identify deviations from the plan. The model was implemented in an ongoing construction project, in which a computerized DSR was used. The results of this test were positive.

The APPC program is currently focusing on ways in which project monitoring can be further improved through a seamless integration of both manually and automatically collected data. For example, data on the workers currently engaged in activities on the site, which is automatically collected by tracking the workers’ locations, can be combined in one model with data on the completion of activities, which is manually recorded in a computerized DSR. Such a model could accurately monitor in real time the actual labour inputs in a project, and avoid the problems which occur when a fully automated or fully manual approach is employed. By linking such a model with the project schedule, significant deviations from the schedule could be identified. The significance of deviations depends, of course, not only on their size, but also on their knock-on effects, which may cause additional deviations in the future. These effects can be identified by updating the schedule in real-time according to the deviations that have occurred.

Project Control

While project monitoring deals with the identification of significant deviations from the planned project performance, project control deals with the measures necessary to correct or minimize these deviations. Controlling measures include corrective actions such as rescheduling activities, requesting design changes and allocating additional resources. Such measures often have an unexpected indirect impact on the entire project, which may eventually cause the project to deviate even more from the planned performance. For example, an attempt to reduce a deviation from the schedule by carrying out additional activities simultaneously may cause conflicts and difficulties in integrating these activities, resulting in additional downstream work and further delays. The indirect impact of such changes on the project is difficult to predict, and often becomes clear only after the changes are fully implemented.

The APPC program included the development of a graph-based model to facilitate the assessment of the possible impact of changes, prior to their implementation in the project. Different graph-theoretic tools and algorithms are used in order to integrate and update the information in the model, and to automatically identify the project's elements (e.g. resources, construction activities, building components) and objectives (e.g. duration, cost, performance) that could be affected by a proposed measure. Once the affected elements are identified, the possible magnitude of the impact of the proposed measure on these elements has to be analyzed. It was found, however, that for a quantitative analysis of the size of an impact, a manual input is required as well.
The attributes of project elements often include tolerance margins, or buffers, in their definition. Buffers are a gap between the (required) minimal and (actual) defined attributes of an element:

- The specification of requirements in the building program which exceed the minimum necessary to accommodate the planned user activities.
- The design of building components with a capacity larger than that required in order to fulfill the requirements in the building program.
- The allocation of resources in the project plan which exceed the minimum required for the planned tasks.

Such buffers may partly or wholly absorb the impact of a change before it reaches a project element. For example, it may be possible to absorb the impact of additional work through time buffers in the schedule, so that it will not cause any delays. Some buffers, such as contingencies in the budget and time buffers in the schedule, are explicitly documented, and can be automatically identified. Yet, other buffers are often not recorded when decisions are made to allocate them, and are difficult to identify automatically. For example, tolerance margins that are incorporated in the design are often not documented (though they may be revealed through the use of building simulation software). Furthermore, the size of buffers that can be used to absorb the impact of changes may vary during a project, depending on external factors. Commitments by sub-contractors to other projects, for example, may reduce resource buffers in the project plan. Team members may have tacit knowledge regarding certain buffers, when these are not explicitly known. For example, a member of the design team is likely to be able to assess the tolerance margin that has been incorporated in a subsystem he has designed. A sub-contractor can probably assess how much additional work he can carry out in the project.

Data on buffers that was manually elicited from project team members was incorporated in the graph-based model. This model was then used for both an automatic identification of the elements that might be affected by a proposed measure, and a manual assessment of the size of this impact. The model was tested through simulations in which experts used it to identify the implications of changes that were presented to them. The model allowed the participants in these tests to make a more accurate assessment, which took into account additional information. As a result of using the model, the participants were reminded of implications they had previously overlooked.

**CONCLUSIONS**

The preliminary results of the APPC program for the development of models for monitoring and controlling construction projects indicate that both automatically and manually collected data are required in these models. In order to incorporate data from manual sources in the models, it has to be represented in a standardized computer-based form. The development of a monitoring model that uses data from a computerized daily site report, and generates information on the actual progress in the project that is then transferred to scheduling software, demonstrated the feasibility of such an approach. The possibility of combining manual and automatic data sources to facilitate better project control was demonstrated with a model that indicated the indirect implications of proposed controlling measures, based on information elicited from project team members, as well as on information produced by graph-theoretic algorithms. While such a hybrid approach shows promise, additional research is still required in order to develop the databases and methods required to fully realize it.

**References**


Cost Effective Sensors for Automated Progress Measurement and Management (APMM)

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Purpose ‘Progress’ is the most often used indicator in construction project management. Nevertheless, excessive management efforts to collect and analyze detailed data have been highlighted as a major barrier for advanced progress management techniques for construction projects. Even though the advent of data acquisition technologies (DATs) provides for automated manipulation of these requirements, previous research efforts have mainly focused on a specific DAT or on the limited construction tasks. In order to effectively utilize DATs for construction projects, a comprehensive approach is desirable, possibly including every single work item within the automated system. The purpose of this paper is to propose such a methodology for integrated utilization of DATs for repeated applications to multiple work items.

Method For the purpose of selecting the most adequate DATs for the most frequent patterns of automated data acquisition methods, we first evaluated a comprehensive evaluation of entire work items for a case-project. The criteria for this selection process are modified and simplified based on the algorithm developed by Kang and Jung. Secondly, DAT candidates for most frequent data acquisition patterns were then systematically examined in order to maximize the benefits of utilizing DATs for construction progress measurement. Results & Discussion We found that the most promising area for automated progress measurement and management (APMM) is to deploy ‘simplified and low-cost sensors’ for monitoring the ‘entrance and exit’ of ‘labors’ into a locator of ‘floor (story)’ level for a building construction. The rationale, techniques, and implications of the proposed methodology are illustrated by a case-project. Recommendations for future research are also discussed.

Keywords: data acquisition technology (DAT), automated progress measurement, sensor, scheduling

INTRODUCTION Cost, schedule, and quality are the three major indicators for successful construction projects. Monitoring these three indicators provides the managers with valuable information in terms of ‘current status’, ‘corrective countermeasure’, and ‘forecast of future risks’. However, the managerial effort (or workload) required to acquire and maintain detailed progress data has been the major barrier to practical implementation. Even though the advent of data acquisition technologies (DATs) provides an automated way to manipulate these requirements, previous research efforts have mainly focused on a specific DAT or on the limited construction tasks. In order to effectively utilize DATs for construction projects, a comprehensive approach possibly including every single work item within this automated system is desirable. Nevertheless, to date, there have been very limited research efforts comprehensively addressing a methodology in order to integrated and optimize the automated tools for effective progress management. In this context, the purpose of this paper is to propose a methodology for integrated utilization of DATs by repeatedly applying the same sensors to multiple work items. For the purpose of selecting the most adequate DATs for the most frequent patterns of automated data acquisition methods, a comprehensive evaluation of entire work items for a case-project was evaluated.

CONSTRUCTION PROGRESS MEASUREMENT The most commonly perceived concept of progress implies the “work completed with the associated cost”. Therefore, progress can be defined as the “actual work completed in terms of budgeted cost” 1. This progress (earned value, or budgeted cost for work performed, EV or BCWP) is used as a baseline to which the planned schedule (budgeted cost for work scheduled, PV or BCWS) and the actual cost (actual cost of work performed, AC or ACWP) are compared to measure the schedule performance and cost performance, respectively. In an effort to automate the progress measurement process, Jung and Kang 1 proposed a concept of standard progress measurement package (SPMP) that enables automated generation of WBS with standard packages and methods based on historical project database and knowledge (Column (a) through (d) in Table 1). One of the distinct characteristics of the SPMP is that each progress measurement package (PMP) has automatically embedded properties specifying the most appropriate types of measurement locator (physical breakdown, e.g. one floor), measurement complexity, and most likely duration. It also evolves as a project’s requirements are changing. The case-
project in Table 1 is a research complex. Specifics of the case-project include: an eleven-story office building and a laboratory, 17,087 m² of total floor area, 19-month project duration.

DATA ACQUISITION TECHNOLOGY (DAT)

Various research efforts have been conducted in order to utilize advanced data acquisition technologies (DATs) in construction. A comprehensive literature survey investigating DAT applications in construction over fifteen years (1993 through 2008) found that 47.3% of DAT applications were for ‘concrete works’ and 25.0% for ‘earthwork’ among many different work sections. In terms of DAT, RFID (36.1%) and GPS (33.3%) are the most often used technologies. As for construction business functions, scheduling (30.7%) was the most popular area for DAT utilization as illustrated in Figure 1. It is also observed that recent researches in photogrammetry and automated pattern recognition are widely exerted. However, these technologies are still under developing and hardly satisfy technical and economic feasibility. Another important notion is that previous studies addressed specific DAT or on the limited construction tasks (e.g. GPS application for earthwork). The objects, from which the automated DAT applications collect data, can be categorized into four types, including labor, material, equipment, and document. The survey by Seo et al. indicated that frequency for material, equipment, and labor as DAT objects were 47.6%, 29.2%, 23.0%, respectively. Among these measuring objects, the labor information is promising area for repeated DAT application for multiple work packages because every work package heavily depends on workers. Nevertheless, previous researches require identifying the locations of specific trades or crews in order to control labor information. For example, Navon and Goldschmidt proposed automated labor monitoring frameworks for automated project performance control which incorporates planning, design, and project control data. Sacks et al. further developed a labor monitoring system by attaching GPS receivers to labors’ helmets. In order to maximize the benefits from DAT, this study attempts to develop a low-cost sensing system for multiple operations to many different work packages within a project.

AUTOMATED PROGRESS MEASUREMENT (APMM)

A series of research efforts for automated progress measurement and management (APMM) has been conducted at Myongji University in Korea. This paper is part of consecutive researches as described in Figure 2. The first step was automating work breakdown structure (WBS) generation. It was found that standardized WBS can be automatically generated by using historical database and construction knowledge. It was of great importance in practice because less experienced engineers on the job site have difficulties in formulating WBS, and WBS is a starting point for progress measurement for any project. The second step was developing a methodology to automatically assign most appropriate measurement method (e.g. physical measurement, earned value, estimated percent complete) to each work package. The result from these two automated steps is shown in Column (a) through (d) in Table 1. After automatically generating the work packages with assigned measurement methods (PMPs in Table 1), as the third step, it is necessary to assign most effective DAT to every single work package. Kang and Jung developed a methodology in order to automate this DAT evaluating and assigning process. The characteristics of PMPs and DATs are organized in a structured manner so that knowledge can be accumulated for DAT selection. Column (e) through (h) in Table 1 lists the result of this automated DAT selection process. Finally, the fourth step is to identify work packages (PMPs) those can share the same DAT application for repeated utilization.

Fig. 1. DAT Applications in Construction Literature (Seo et al. 2009)

Fig. 2. Automated Progress Measurement and Management (APMM) Research at Myongji University
Table 1. Result of automated PMP generation and automated DAT selection for a case-project

<table>
<thead>
<tr>
<th>(a) ID</th>
<th>(b) Measurement Package (PMP)</th>
<th>Characteristics</th>
<th>Automated Data Acquisition Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB10</td>
<td>Excavation &amp; Fill</td>
<td>A section</td>
<td></td>
</tr>
<tr>
<td>BC10</td>
<td>Scaffolding and Temporary</td>
<td>One building</td>
<td></td>
</tr>
<tr>
<td>BC3010</td>
<td>Cast-In-Place Concrete</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BC3020</td>
<td>Reinforcing Steel</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BC3030</td>
<td>Plant-Precast Concrete</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BC3040</td>
<td>Structural Steel</td>
<td>An assembly</td>
<td></td>
</tr>
<tr>
<td>BC3050</td>
<td>Steel Erection</td>
<td>An assembly</td>
<td></td>
</tr>
<tr>
<td>BC3060</td>
<td>Steel Deck</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BC60A</td>
<td>Brick Masonry</td>
<td>Two floors</td>
<td></td>
</tr>
<tr>
<td>BC60B</td>
<td>CMU</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BD10</td>
<td>Roofing Accessories</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE20A</td>
<td>Cementitious Waterproofing</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE20B</td>
<td>Sheet Waterproofing</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE20C</td>
<td>Fluid-Applied Waterproofing</td>
<td>One floor</td>
<td></td>
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<td>BE20D</td>
<td>Special Waterproofing</td>
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<tr>
<td>BE2505</td>
<td>Joint Sealants</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2510</td>
<td>Cement Plaster (Interior)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2515</td>
<td>Cement Plaster (Floor)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2530</td>
<td>Cement Plaster (Stair)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2535</td>
<td>Coatings for Concrete</td>
<td>Two floors</td>
<td></td>
</tr>
<tr>
<td>BE2540</td>
<td>Concrete Finishing</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2545</td>
<td>Insulation Mortar</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE2560</td>
<td>Cementitous Decks</td>
<td>Two floors</td>
<td></td>
</tr>
<tr>
<td>BE30A</td>
<td>Ceramic Tile (Floor)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE30B</td>
<td>Stone Tile</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE30C</td>
<td>Ceramic Tile (Wall)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE35A</td>
<td>Stone Flooring (Exterior)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE35B</td>
<td>Stone Facing (Interior)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE35D</td>
<td>Stone Facing (Exterior)</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE35H</td>
<td>Stone Jams and Sills</td>
<td>One building</td>
<td></td>
</tr>
<tr>
<td>BE35K</td>
<td>Metal Truss</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE40A</td>
<td>Stainless Steel Handrails</td>
<td>A stairwell</td>
<td></td>
</tr>
<tr>
<td>BE40D</td>
<td>Gratings and Trenches</td>
<td>A section</td>
<td></td>
</tr>
<tr>
<td>BE40E</td>
<td>Aluminum Metal Fabrication</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE40F</td>
<td>Aluminum Ceiling</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE40G</td>
<td>Fan Coil Unit Covers</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE40H</td>
<td>Miscellaneous Metalwork</td>
<td>One building</td>
<td></td>
</tr>
<tr>
<td>BE5005</td>
<td>Steel Doors</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE5010</td>
<td>Stainless Steel Doors</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE5015</td>
<td>Aluminum Windows</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE5030</td>
<td>Hardware</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE55A</td>
<td>Glazing (Interior)</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE55B</td>
<td>Glazing (Exterior)</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE60A</td>
<td>Painting (Interior)</td>
<td>Three floors</td>
<td></td>
</tr>
<tr>
<td>BE60B</td>
<td>Painting (Exterior)</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE60C</td>
<td>Painting (Misc)</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE65A</td>
<td>Resilient Flooring</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE65B</td>
<td>Acoustical Wall</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE65C</td>
<td>Building Insulation</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE65D</td>
<td>System Furniture</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE65E</td>
<td>Compartments and Cubicles</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE65F</td>
<td>Ceiling</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE65G</td>
<td>Gypsum Board Assemblies</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE70A</td>
<td>Cementitious Fireproofing</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE70B</td>
<td>Acoustical Wall</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE70C</td>
<td>Building Insulation</td>
<td>One floor</td>
<td></td>
</tr>
<tr>
<td>BE75</td>
<td>Miscellaneous Finishing</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE8010</td>
<td>Planting</td>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>BE8020</td>
<td>Pavement &amp; Landscape</td>
<td>Project</td>
<td></td>
</tr>
</tbody>
</table>

**Columns (a), (b), (c), (d) are from Jung and Kang (2007), and columns (e), (f), (g), (h) from Kang and Jung (2012)**
DAT APPLICATIONS FOR MULTIPLE WORK PACKAGES

The result from steps one through three in Figure 2 is listed in Table 1. The case-project has sixty-one PMPs (work packages without locators, e.g. concrete) and 233 network scheduling activities (work packages with locators, e.g. 1st floor concrete). Automated data acquisition methods for these sixty-one PMPs are illustrated in the Column (e) through (h) of Table 1 and in Figure 3. It is noteworthy that ‘in and out’ information of ‘labor’ into a locator of ‘floor (story)’ is most often used method among these sixty-one PMPs. Thirty-four PMPs out of sixty-one (55.6%) have the exactly same DAT requirements; The common conditions are ‘labor’ as object (column e), ‘locator’ as range (column f), ‘in and out’ as data type (column g), and ‘RFID’ as DAT type (column h).

Therefore, the thirty-four activities under these common conditions are chosen in this study as being the most promising area for repeatedly using the same sensing technology. For this chosen type of activities, several different DAT candidates are examined including RFID active, RFID passive, and simple motion sensors.

While the RFID applications can collect precise and rich information, it has a couple of drawbacks. For example, in this case-project, every worker should carry a RFID tag whenever he or she is in the job site. Another point is that a RFID reader should be place on every floor in order to collect ‘locator-specific’ information. The cost for RFID reader on every floor (or locator) is also relatively high.

Again, even though RFID or GPS is a good solution, it requires every single laborer carry one device. Under harsh out-door construction job site environment, this requirement is a big burden in terms of cost, maintenance effort, and even workers’ productivity.

Finally, using motion sensors was examined as a solution. A good example is the sensor used in a lighting fixture for energy savings. Motion sensors are used everywhere for automatically switching on and off the lightings. Advantages of motion sensors include no need to carry a device, the low cost, easiness to acquire, and simplicity of device. On the other hand, the most important drawback is that it cannot identify individual, crew, or trade.

In order to solve this problem, requirements for using motion sensors for progress measurement are studied as listed in Table 2.

Initially, the proposed motion sensor system needs labor activity information. In other words, daily distribution of laborers for all thirty-four activities should be calculated for each locator (i.e. floor in this case-project). After calculating the labor distribution, one motion sensor needs to be installed to collect movement of labors within that locator. Next step is to transmit those data to a receiver. Finally, the data received will be compared against planned data in order to determine the completion of a work package based on a daily time scale.

Table 2 summarizes the advantages, drawbacks, requirements for overcome the drawbacks, and logical sequence of proposed ‘motion sensor based progress measurement system’.

Table 2. Motion sensors as APMM DAT

<table>
<thead>
<tr>
<th>Advantages</th>
<th>A1 No need to carry a device (laborer)</th>
<th>A2 Low cost</th>
<th>A3 Easiness to acquire</th>
<th>A4 Simplicity of device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawbacks</td>
<td>D1 No information of individual &amp; trade</td>
<td>D2 No information of the exact location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements as DAT</td>
<td>R1 Prerequisite labor activity information</td>
<td>R2 One sensor required for each locator</td>
<td>R3 Transmitter required for each locator</td>
<td>R4 Algorithm for progress measurement</td>
</tr>
<tr>
<td>Systems Development</td>
<td>S1 Calculating daily labor distribution</td>
<td>S2 Analyze distribution patterns</td>
<td>S3 Collect motion data</td>
<td>S4 Compare motion data against S2</td>
</tr>
</tbody>
</table>

Fig. 3. Automated Progress Measurement Patterns of Case-Project (Kang & Jung 2012)

MOTION SENSORS FOR LABOR MONITORING

In order to develop economically effective and feasible DAT applications, several different options for the thirty-four work packages (measuring ‘in and out’ information of ‘labor’ into a locator of ‘floor’), were analyzed.
ANALYZING LABOR DISTRIBUTION FOR APMM

This study is on-going and still under further development. By using the case-project, technical feasibility of proposed system is examined.

For the first step of systems development in Table 2 (S1 ‘calculating daily labor distribution’), labor distribution was calculated. For the purpose of initial analysis and easier understanding, six activities from thirty-four work packages are selected and modeled in Table 3 and Figure 4. Six activities include formwork (BC3020 in Table 1), reinforcing steel (BC3030), concrete (BC3010), brick masonry (BC60A), plastering (BE2505), and ceramic tile (BE30A).

A CPM schedule was developed for these activities for a ten story building. A linear scheduling method (LSM) was also used to facilitate effective resource (labor) leveling and sequencing. The values of standard crew mix and daily output are applied to calculate the required number of laborers for the activities as described in Table 3 (e.g. 13 laborers are required to complete concrete work for one floor). Finally, number of laborers per day and duration for each activity are calculated and summarized by locator (floor) as well as by project total (Figure 4 and Figure 5).

Table 3. Productivity and Required Labor (per locator)

<table>
<thead>
<tr>
<th>ID</th>
<th>BC3010</th>
<th>BC3020</th>
<th>BC3030</th>
<th>BC60A</th>
<th>BE2505</th>
<th>BE30A</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMP</td>
<td>Concrete</td>
<td>Formwork</td>
<td>Reinforcing Steel</td>
<td>Brick Masonry</td>
<td>Cement Plaster</td>
<td>Ceramic Tile</td>
</tr>
<tr>
<td>Unit</td>
<td>m3</td>
<td>m2</td>
<td>ton</td>
<td>1000 ea</td>
<td>m2</td>
<td>m2</td>
</tr>
<tr>
<td>Quantity</td>
<td>180</td>
<td>666</td>
<td>337</td>
<td>46</td>
<td>272</td>
<td>16</td>
</tr>
<tr>
<td>Crew Size (No. of Laborer)</td>
<td>13</td>
<td>6</td>
<td>8</td>
<td>5</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Labor Hours (Per unit)</td>
<td>0.0</td>
<td>0.1</td>
<td>0.2</td>
<td>2.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Total Labor</td>
<td>13</td>
<td>94</td>
<td>88</td>
<td>101</td>
<td>71</td>
<td>6</td>
</tr>
<tr>
<td>No. of Crews (per locator)</td>
<td>1.0</td>
<td>15.7</td>
<td>11.0</td>
<td>20.2</td>
<td>11.8</td>
<td>3.1</td>
</tr>
<tr>
<td>No. of Crews (per day)</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Duration (Day)</td>
<td>1.0</td>
<td>3.1</td>
<td>1.8</td>
<td>4.0</td>
<td>2.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Activity Profile</td>
<td>Uneven</td>
<td>Even</td>
<td>Even</td>
<td>Even</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IDENTIFYING LABOR DISTRIBUTION PATTERNS

Figure 5 shows that there are two different major factors characterizing labor distributions of CPM activities. One is whether an activity requires lag time between floors within the same PMP (discrete, D) or not (continuous, C). Concrete is the case; it requires curing between floors. The second pattern is the shape of labor distribution curve within an activity. For example, while concrete (including formwork and reinforcing steel) has an uneven (U) distribution, brick masonry has an even (E) distribution throughout the activity’s entire duration.

These two factors give four combinations, discrete uneven (D-U), discrete even (D-E), continuous uneven (C-U), and continuous even (C-E). In Figure 4 and 5, concrete work is discrete and uneven (D-U), and brick masonry, cement plaster, and ceramic tile are continuous even (C-E) as listed in Table 4.

These patterns provide indirect clues for progress measurement. For example, because the concrete work has uneven distribution, decrease of labor members on 6th day for each floor indicates that concrete pouring is started on that floor. Decrease of labor members by 13 on 7th day means concrete pouring was completed and curing has been started.
Table 4. Patterns of Labor Distribution between Locator

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Inference</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-U</td>
<td>Partial completion &amp;</td>
<td>Concrete</td>
</tr>
<tr>
<td></td>
<td>Completion detected</td>
<td>(w/ form &amp; re-bar)</td>
</tr>
<tr>
<td>D-E</td>
<td>Completion detected</td>
<td>Steel structure</td>
</tr>
<tr>
<td>C-U</td>
<td>Partial completion &amp;</td>
<td>Stone cladding</td>
</tr>
<tr>
<td></td>
<td>Completion detected</td>
<td>(w/ frame)</td>
</tr>
<tr>
<td>C-E</td>
<td>Completion detected</td>
<td>Brick Masonry</td>
</tr>
</tbody>
</table>

By combining and comparing data from planned distribution of each floor (Figure 4), planned distribution of all floors (Figure 5), and data from actual distribution on the job site, completions of activities can be automatically measured.

**Motion Sensor Based APPM System**

By using the progress measurement algorithm introduced in previous chapters, a motion sensor based APPM system is proposed. The system is composed of three modules. First module is the DAT module. A motion sensor is attached to a RFID active device. This module is installed at every locator (floor in this case-project). Therefore, for a ten story building, ten RFID actives are required. However, this module has only one RFID reader. Transmission between ten RFID actives and one reader is designed to use wireless channels for easier maintenance on the job site. The second module includes algorithms for automated pattern recognition. Data from planned schedule is converted to daily labor distribution as depicted in Figure 4 and 5. Final module is to input engineers’ final decision. Automatically generated progress information will be summarized and reported for engineers’ approval. This process should be performed on a daily basis. The prototype system is under development and is under patent pending.

**Conclusions**

Progress measurement is one of the most critical tasks for successful project performance management. Maintaining accurate and timely progress information demands extra managerial overhead cost. In order to solve this problem, rigorous research efforts have been exerted to automate the data collection process by using sensors. Nevertheless, previous researches have mainly focused on a specific DAT or on the limited construction tasks. In this context, the purpose of this paper was to propose a methodology for integrated utilization of DATs by repeatedly applying the same sensors to multiple work items. Based on evaluations of DATs and work packages of a case-project, candidates for the repeated applications were identified. Motion sensor is selected as being the low cost DAT, and algorithms for implementing the proposed application were developed. It is found that 56% of work packages can be measured by using the same sensors repeatedly. Another notion is that this paper tried to fully automate the progress measurement of an entire construction project instead of limited work packages. It is found that the most promising area for automated progress measurement and management (APMM) is to deploy ‘simplified and low-cost sensors’ for monitoring the ‘entrance and exit’ of ‘labors’ into a locator of ‘floor (story)’ level for a building construction.

**Acknowledgements**

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**References**

New sampling scheme for neural network-based metamodelling with application to air pollutant estimation

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Purpose
A new method for the design of experiments (DOE) or sampling technique is proposed, using a distance weight function and the k-means theory. The radial basis function neural network metamodelling approach is used to evaluate the performance of the proposed DOE by using an n-degree of test function, applied to the complex nonlinear problem of spatial distribution of air pollutants. A comparison study is included to analyse the performance of the proposed technique against available methods such as the n-level full fractional design method and the Latin Hypercube Design method.

Method
For one design objective and n number of input design variables, a set of input-output training dataset are

\[ X = \{x_1^{(1)}, x_1^{(2)}, ..., x_j^{(1)}, x_j^{(2)}, ..., x_k^{(1)}, x_k^{(2)} \} \]

and

\[ Y = \{y^{(1)}, y^{(2)}, ..., y^{(m)} \} \]

where m is the maximum number of the data points. Each data point has its own unique weight obtained from the distance factors between point \( p \) and a common reference point \( c \), by using the Euclidean distance measure (i.e. \( d(p, c) \)). The weights represent the distinct patterns between each data point. A neighbour can be clustered as a group where the data point is taken as a candidate. To generalise the solution, the pairs of the input and output data points are combined to become the design space, given as

\[ S = \{X, Y\} \].

The solution can be simplified further if we set a common reference centre at the coordinate origin by firstly normalising the design space to \( \tilde{S} = \{-1,1\}^n \). A list of distance weight values, \( D = [d_1, d_2, ..., d_m] \) is then sorted and clustered by using an available clustering algorithm. In this work, the k-means algorithm based on the Voronoi iteration is used due to its fast computation especially in the 1-dimensional case.

Results & Discussion
To initially validate the accuracy of the scheme, a known test function called as "Hock–Schittkowski Problem 100" is used in which this nonlinear problem involving of 7 variables, 1 objective, and 4 constraints. A prepared dataset which generated randomly, are sampled at different sample size \( N \), and then mapped using RBFNN metamodel.

INTRODUCTION
Nowadays, simulation modelling becomes a popular tool for the analysis of complex systems' behaviour. Its popularity is due to the flexibility in the implementation and the ability to model a real world physical system to a certain detail. A deterministic type model has shown good performance in its estimation, but encounters difficulties in the development and highly computational cost in the execution. Thus, metamodels (or surrogate models) have been suggested to be an approximate model that can adequately represent the intrinsically non-linear and complex relationship between the system's input and output.

Before executing the function approximation in metamodelling, it is important to select the design points in the domain which is generally termed as sampling, experimental design, or design of experiment (DOE). The aim of any sampling method is to effectively cover the design space and to gather the essential information of the design space characteristics. These sets of independent design variable values from the data points are utilised to produce the values of dependent variables (i.e. responses), in a process known as computer experiments. Various sampling approaches appeared in the literature such as the full factorial design technique, stratified random sampling, Latin square sampling and Latin Hypercube sampling.

This paper presents a new strategy for a metamodel DOE, based on the distance measure and clustering process, referred to as the weighted clustering design (WCD) throughout this paper. Here we employ
the proposed sampling method to develop a radial basis function neural network (RBFNN) metamodel as a function approximator. We first test the scheme validity with a known nonlinear function. The air pollutant estimation problem is then tackled by using the improved metamodel.

The rest of this paper is arranged as follows. An overview on experimental design is discussed after the introduction. The following section describes in detail the methodology which covers the proposed sampling scheme, the implementation of RBFNN as a metamodel, and the performance measure to validate the model. The next section presents the results together with a discussion on the underlying simulation problem, followed by some concluding remarks given in the final section.

**OVERVIEW OF SAMPLING SCHEME**

The primitive experimental design involves the selection of few data points located at the bounds of the design space, and is called the full factorial array. This is a physical trial method in which the effectiveness of using these points remains very poor. In the computers’ era, the experimentation became less costly and the space filling experimental designs started to be used. The full factorial design (FFD) is the simplest sampling approach which is the most general and standard DOE used over the years for the function approximation purpose. In FFD, the bounds of all the design variables are firstly identified and then discretised into equal intervals within the design space. For example, for n-level FFD, the total number of points selected for each design variable is equally spaced over the range. It means the number of design points will be n^v. This approach is also known as the rectangular grid point sampling.

Another space-filling method called the Plain Monte Carlo sampling involves using a random number generator to select the points to reduce the number of points in a trial set. While being computationally-efficient, Monte Carlo sampling provides no robustness in finding a space filling set of points. The Latin Hypercube Design (LHD), proposed by McKay et al., is a more sophisticated sampling scheme and continuously being researched. Instead of using all equally-spaced points in the allowable design space, these points are effectively scattered, spanning the whole domain. For selection of n number of sample points, the range of each design variable is divided into the same number of non-overlapping regions based on the type of probability distribution function (PDF) specified, which can be either normal or uniform PDF. One segment is chosen from each region at random to form each trial point. As there is no guarantee for a balanced set to be obtained from the points, many researchers have extended the McKay method into optimal LHD, inherited LHD, and hybrid LHD.

**METHODOLOGY**

Metamodelling research has been a major research field during the last decade. Basically, metamodels are constructed in three stages, i.e. preparing the data and choosing the modelling approach; parameter estimation and training; and model validation and testing. In neural network based metamodelling, the data sampling is necessary to reduce the computational burden especially when dealing with a large dataset. The methodology of the proposed sampling scheme is described in the following subsection.

**The proposed sampling scheme**

Here, a dataset are normally divided into two, one for the training (trial) and another one for the testing. If we have a set of input-output training dataset denoted by x and y, a mapping solution is given as follows:

$$x^{(i)} \rightarrow y^{(i)} = f(x^{(i)}) \quad i = 1,2, ..., m,$$

(1)

where m is the maximum number of the data points. For the case of one design objective and n number of input design variables, the input and output are given as in the following equations,

$$x = [x_1^{(1)}, x_1^{(2)}, ..., x_1^{(n)}; ..., x_i^{(1)}, x_i^{(2)}, ..., x_i^{(n)}; ..., x_n^{(1)}, x_n^{(2)}, ..., x_n^{(n)}] \quad i = 1,2, ..., n$$

and

$$Y = [y^{(1)}, y^{(2)}, ..., y^{n}] \quad i = 1,2, ..., m,$$

(2)

For a 3-dimensional problem, the distribution of four data points is illustrated in Fig.1. Each data point has its own unique weight by measuring the distance weight factors from a common reference point c. By using the Euclidean distance measure, the distance between point p and c is mathematically written as,

$$d(p,c) = \left[ (p_x - c_x)^2 + (p_y - c_y)^2 + (p_z - c_z)^2 \right]^{1/2}$$

(3)

or generally, the weight for all data points of the n-dimensional problem is given as follows:

![Fig.1. A distribution of data points in 3-dimensional space.](image)
\[
    d(p', c) = \left[ \sum_{i=1}^{n} \left( p'(x_i) - c(x_i) \right)^2 \right]^{1/2}.
\]

The weights could represent the distinct patterns between each data point, and some neighbour points may have about similar weight that could be clustered as a group and one point is taken as a candidate.

To generalise the solution, the pairs of the input and output data points are combined to become the design space \( S \) in this evaluation, which is given as

\[
    S = \{ X; Y \}.
\]

Hence, the dimension of distance measures for one targeted output now becomes \((n+1) \times m\). The solution (4) can be simplified further if we set a common reference centre at the origin 0 by firstly normalising the design space \( S \) to the minimum of -1 and to the maximum of 1, i.e.

\[
    S' = [-1, 1]^{(n+1) \times m},
\]

as shown in Fig. 1. Thus, solution (4) now becomes

\[
    d(p') = \left[ \sum_{i=1}^{n+1} \left( p'(\hat{x}_i) \right)^2 \right]^{1/2},
\]

where \( \hat{x}_j \) is the normalised values of the design space \( S \) which has been incorporated by the output variable.

A list of distance weight values

\[
    D = \{ d_1, d_2, ... , d_i | i = 1, 2, ..., m \}
\]

is then sorted and clustered by using available clustering algorithm. In this work, a well-known \( k \)-means algorithm based on Voronoi iterations is used due to its fast computation especially for the 1-dimension case. It uses a two-phase iterative algorithm to minimise the sum of point-to-centroid distances, summed over all \( k \) clusters. There are several methods to choose the initial \( k \)-means points. In this evaluation, we replicate them randomly, which typically results in a solution that is a global minimum. The maximum number of cluster \( k \) corresponds to the number data points to be sampled. The determination of an appropriate \( k \) value for this scheme is demonstrated in this work.

Radial basis function network as metamodel

There are a number of metamodeling techniques that have been researched such as polynomial regression, splines, neural networks, Kriging, and support vector machine.\(^{10,12} \) A few attempts have been made to employ radial basis function neural networks as the metamodeling technique (see e.g. by Liu et al.\(^{13} \) and Ma et al.\(^{14} \)).

The RBFNN is a special type of feed forward neural network architecture which consists of an input layer, a hidden layer and an output layer. The neurons in the hidden layer work are the processing elements to perform a non-linear transformation of the input data to approximate the output data. The RBFNN’s \( q \) outputs corresponding to the input vector \( x \in \mathbb{R}^n \) is mathematically represented as follows:

\[
    f_i(x) = \sum_{k=1}^{n} w_{kj} \phi(||x - c_k||_2), \quad i = 1, 2, 3, ..., q
\]

where \( \phi() \) is a basis function, \( \| \|_2 \) denotes the Euclidean norm, \( w_{kj} \) are the weights in the output layer, \( n \) is the number of neurons (and centres) in the hidden layer and \( c_k \in \mathbb{R}^n \) are the RBF centres in the input vector space.

In practice, several forms of the basis function \( \phi \) are used for RBF models, and Gaussian is probably the most popular one because it has attractive mathematical properties of universal and best approximation, and its bell shape is easy to control with the spread parameter \( \sigma \). In this work, a generalised radial basis function neural network (RBFNN) approach is considered, in which fixed biases \( b \) are added at the outputs to solve the ill-posed problem relating to singularity (e.g. an approach to regularise the network)\(^{15} \). For a Gaussian GRBFNN, equation (9) becomes

\[
    f_i(x) = \sum_{k=1}^{n} w_{kj} \exp(-||x - c_k||_2^2/2\sigma^2) + b
\]

At the hidden and output layer, the position of the radial basis centres, the variance (spread) and the associated linear weights are all unknown parameters that have to be updated. A supervised learning process using a forward selection procedure\(^{16} \) is implemented to select the position of the centres and a linear least square method is used to train the weights and biases of the output layer.

Metamodel validation

The accuracy of the estimation via metamodeling is evaluated to ensure that the metamodel reflects the actual model. In this evaluation, some statistical indexes will be used for the residual errors, including the root mean square error (RMSE), the mean absolute error (MAE) and the determination coefficient \( (R^2) \), and to use the index of agreement, \( d_z \), a measure expressing the degree to which predictions are error-free\(^{17} \).

**TEST RESULTS AND ANALYSIS**

To evaluate the effectiveness of the proposed approach, we first use a benchmark test problem, namely, the Problem 100 from Hock–Schittkowski\(^{18} \), and then apply it to the problem of estimating the spatial distribution of the ozone concentration in air pollution modelling. For each problem considered, different sample sizes and fitting design methods including weighted clustering design (WCD), n-level full factorial design (n-FFD) and Latin Hypercube design (LHD), are considered. Some of the perform-
formance measures, the size of RBFNN metamodel and the total execution time for the simulations are recorded.

**Benchmark Test: Multidimensional function**

The Hock–Schittkowski Problem 100 is a test problem consisting of seven variables, one objective, and four constraints. In this analysis, we consider only the objective function without constraints. The design domain for this function is given by

\[
f(x) = (x_1 - 10)^2 + 5(x_2 - 12)^2 + x_3^4 + 3(x_4 - 11)^2 + 10x_5^4 + 7x_6^2 + x_7^4 - 4x_4x_7 - 10x_5 - 8x_6,
\]

(11)

where \(-10 \leq x_i \leq 10\). To prepare a full large dataset, a series of input-output data points are randomly generated (e.g. using ’randn’ code in Matlab) within the design space in which the maximum number of data points is set to 4000.

By using three experimental design methods, the prepared data are sampled at a different sample size, \(N\). Each set of the sampled data is then mapped using the RBFNN metamodel by setting the spread parameter as 4 and the prescribed \(mse\) goal as 0.001 for all the testings.

Table 1 shows the results for three types of analysis which involve the performance indexes, the number of hidden neurons used to construct the neural network and also the total simulation time. For the proposed sampling scheme, the performance based on \(R^2\) and \(d_2\) is increased with the increment corresponding to \(N\), which approaches 1 for the possible best performance. However, to compromise between the performance and the complexity of the approximate model, for a large dataset, the sample size \(N\) may be selected at between 25% and 30% from the full dataset. The reason is that no significant improvement on the performance is expected for \(N\) greater than this value, due to saturation. Notably, the produced \(RMSE\) and the \(MAE\) values are relatively small (about ±4% errors) as compared to the maximum output value for the test problem.

Next, the other two design methods are executed by using the same metamodel configurations. For the \(n\)-level FFD method, each design variable is assigned with a different number of levels as to generate the different sampling sizes. For example, the [2 3 3 2 3 3 3] configuration will give 972 sampling points' location, which is the product of the number of levels for each dimension. This design approach is in a uniform fashion, by means of a rectangular grid of points. For the LHD technique, a ‘maximin’ metric, introduced by Johnson et al., is considered in this study. This approach yields a randomised sampling plan with projections uniformly-spread onto the axes.

As compared to the \(n\)-level FFD, at the same sample size, the proposed scheme (i.e. WCD) shows a certain improvement in the size of constructed neural networks, and produces nearly similar performance on the error indications. In the other comparison, the LHD requires about similar network size as WCD, however exhibiting poor performance. Thus, in general, by compromising between the computational cost (i.e. execution time and the network size) and the performance of the model, the WCD method offers a better sampling solution. An example of the estimated output for the case when the sample size is 30 percent of the full dataset is shown in Fig. 2.

Therein, the constructed metamodel is able to accu-

---

**Table 1. Metamodel comparison results for Test 1 problem. (Note: full dataset number, \(N_{full}=4000\), \(sp=4\), \(mse=0.001\))**

<table>
<thead>
<tr>
<th>No.</th>
<th>Design name</th>
<th>Details</th>
<th>Sample size, (N)</th>
<th>% of (N)</th>
<th>Performance measure</th>
<th>Network size</th>
<th>Simulation time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>WCD</td>
<td></td>
<td>400</td>
<td>10</td>
<td>RMSE: 1.79E06, MAE: 1.23E06, (R^2): 0.443, (d_2): 0.861</td>
<td>298</td>
<td>42</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td>600</td>
<td>15</td>
<td>RMSE: 1.09E06, MAE: 7.39E05, (R^2): 0.793, (d_2): 0.948</td>
<td>329</td>
<td>57</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td>1000</td>
<td>25</td>
<td>RMSE: 4.84E05, MAE: 3.39E05, (R^2): 0.960, (d_2): 0.990</td>
<td>330</td>
<td>93</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td>1400</td>
<td>35</td>
<td>RMSE: 4.18E05, MAE: 2.98E05, (R^2): 0.971, (d_2): 0.993</td>
<td>333</td>
<td>126</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td>1800</td>
<td>45</td>
<td>RMSE: 3.69E05, MAE: 2.68E05, (R^2): 0.976, (d_2): 0.994</td>
<td>333</td>
<td>173</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
<td>2200</td>
<td>55</td>
<td>RMSE: 3.46E05, MAE: 2.58E05, (R^2): 0.980, (d_2): 0.995</td>
<td>337</td>
<td>250</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
<td>2800</td>
<td>70</td>
<td>RMSE: 3.14E05, MAE: 2.32E05, (R^2): 0.983, (d_2): 0.996</td>
<td>341</td>
<td>369</td>
</tr>
<tr>
<td>8.</td>
<td></td>
<td></td>
<td>3400</td>
<td>85</td>
<td>RMSE: 3.26E05, MAE: 2.40E05, (R^2): 0.982, (d_2): 0.995</td>
<td>342</td>
<td>495</td>
</tr>
<tr>
<td>9.</td>
<td>n-FFD</td>
<td>[2 3 3 2 3 3]</td>
<td>972</td>
<td>24</td>
<td>RMSE: 4.66E05, MAE: 3.27E05, (R^2): 0.962, (d_2): 0.991</td>
<td>351</td>
<td>99</td>
</tr>
<tr>
<td>10.</td>
<td>'n-levels'</td>
<td>[2 3 3 3 3]</td>
<td>1458</td>
<td>36</td>
<td>RMSE: 3.70E05, MAE: 2.66E05, (R^2): 0.976, (d_2): 0.994</td>
<td>349</td>
<td>143</td>
</tr>
<tr>
<td>11.</td>
<td>LHD</td>
<td>with 'maximin' criterion</td>
<td>1000</td>
<td>25</td>
<td>RMSE: 5.74E05, MAE: 3.93E05, (R^2): 0.943, (d_2): 0.986</td>
<td>334</td>
<td>89</td>
</tr>
<tr>
<td>12.</td>
<td></td>
<td></td>
<td>1400</td>
<td>35</td>
<td>RMSE: 5.02E05, MAE: 3.38E05, (R^2): 0.956, (d_2): 0.989</td>
<td>334</td>
<td>127</td>
</tr>
</tbody>
</table>
rately approximate the true values at most of the points, except for the lower parts (i.e. less than 0 level).

Application: Spatial distribution of air pollutant level

Protecting air quality is essential for the benefits to the public as well as the environment. The air pollution may cause many health problems such as lung disease, asthma and also associated with cancer for some pollutants. It is also affecting the environment by causing some harmful influence to soil, crops, forest, water and wildlife. Thus, authorities are responsible to determine a suitable management policy to protect the air quality. One effective approach is by using data measurement from various monitoring stations across the region. Unfortunately, this is limited to the location of interest. Spatial distribution estimation is an alternative solution to overcome this issue.

In this work, the proposed method of experimental design is applied to spatial estimation for the surface ozone (O₃), recognised as an air pollutant in the tropospheric layer of the atmosphere, of an urban area. This is a very nonlinear and complex estimation task that requires expensive computation. Typically, the dispersion models are used to handle this task, however, they need special software and require a long time in the computational execution. Therefore, a metamodel approach based on neural networks can be used to avoid this complexity as well as to reduce the simulation time.

Spatial estimation model

The functional form of the input-output relationship is not known explicitly because the simulation is a black box. However, from the initial result of a dispersion model, it is suggested that the spatially-distributed ozone levels across the region under consideration is a function of the grid coordinate, topographical information, solar radiation and the ozone’s precursor emission, as illustrated in Fig. 3. The background of the problem’s design variables will not be discussed in details here (i.e. it is described comprehensively in another parallel work), as this work concerns on the assessment of the sampling designs’ performance.

The x-y coordinates represent the cells’ location (in km) in x and y directions. To improve the estimation, topography information is added, consisting of the height information above the sea level (in m) at each domain cell. Here, ambient temperature data are used to represent, at each cell, the solar radiation level, which represents a good indicator for proxy variables to the formation of ozone. Basically, there are two important classes of precursors involved in the formation of ozone: volatile organic compounds (VOCs) and Nitrogen Oxides (NOₓ), however, only NOₓ is to be considered in the modelling as VOCs’ concentrations apparently cannot be measured. The NOₓ emission rates are added from two sources: the gridded inventory emission rate data, extracted from a photochemical dispersion model (deterministic model), and the calculated emission rates to be converted from the measured data by using the Gaussian dispersion function incorporating the wind speed and the wind direction factors. The network output consists of daily n-hour averaged maximum of the ozone concentration (in part per billion, ppb), which is extracted from a deterministic model simulation output. Of interest, 1-hour, 4-hour and 8-hour averages are normally selected in the air quality analysis.

Performance analysis

The methodology has been applied to the Sydney basin in New South Wales, Australia. For preparing the dataset, we use the historical data of NOₓ that were collected at the monitoring stations around Sydney basin by the Department of Environment in

<table>
<thead>
<tr>
<th>No.</th>
<th>Design name</th>
<th>Details</th>
<th>Sample size, N</th>
<th>% of N</th>
<th>Performance measure</th>
<th>Network size</th>
<th>Simulation time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>WCD</td>
<td>525*6</td>
<td>3150</td>
<td>15</td>
<td>RMSE 8.195, MAE 6.256, R² 0.776, MSE 0.944</td>
<td>135</td>
<td>70</td>
</tr>
<tr>
<td>2.</td>
<td>875*6</td>
<td>5250</td>
<td>25</td>
<td></td>
<td>RMSE 7.953, MAE 6.121, R² 0.789, MSE 0.947</td>
<td>147</td>
<td>175</td>
</tr>
<tr>
<td>3.</td>
<td>1225*6</td>
<td>7350</td>
<td>35</td>
<td></td>
<td>RMSE 7.814, MAE 6.011, R² 0.797, MSE 0.949</td>
<td>145</td>
<td>320</td>
</tr>
<tr>
<td>4.</td>
<td>n-FFD</td>
<td>[3 4 4 4 5]*6</td>
<td>5760</td>
<td>27</td>
<td>RMSE 12.275, MAE 8.844, R² 0.498, MSE 0.875</td>
<td>115</td>
<td>162</td>
</tr>
<tr>
<td>5.</td>
<td>‘n-levels’</td>
<td>[4 4 4 4 5]*6</td>
<td>7680</td>
<td>37</td>
<td>RMSE 10.711, MAE 7.927, R² 0.619, MSE 0.904</td>
<td>121</td>
<td>143</td>
</tr>
<tr>
<td>6.</td>
<td>LHD</td>
<td>with ‘maximin’ criterion</td>
<td>5250</td>
<td>25</td>
<td>RMSE 15.021, MAE 10.828, R² 0.248, MSE 0.812</td>
<td>114</td>
<td>134</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
<td>7350</td>
<td>35</td>
<td>RMSE 10.684, MAE 7.922, R² 0.620, MSE 0.905</td>
<td>132</td>
<td>287</td>
</tr>
</tbody>
</table>

Table 2. Metamodel comparison results for Test 2 problem. (Note: Nfull=21000, sp=0.1, mse=0.005)
New South Wales. The rests of the input-output data are extracted from the simulation output of The Air Pollution Model and Chemical Transport Model (TAPM-CTM)\(^2\), a pollution model software developed and used in Australia. For demonstration, the 8-hour averaged concentration was used in this work. For each day, the number of datasets corresponding to the number of cells in the studied domain is equal to 3500 (based on a 2\(\text{km}\times2\text{km}\) grid cell). Six episode days are selected to train the metamodel, thus the full input-output dataset consists of 21000 data points.

By using the same steps as for Test 1, the prepared dataset are sampled at different sample size, \(N\). Using the RBFNN metamodel with the spread parameter of 0.1 and the \(\text{mse}\) goal of 0.005, the performance of each design method is evaluated. The comparison results are shown in Table 2. To prepare the training dataset, full data points for each day are sampled at \(N\) size and summed together. As per the performance indexes shown in the table, the proposed sampling method outperforms the other two methods in terms of error criteria. Both \(n\)-FFD and LHD method require slightly less computation and smaller network size, however, the produced error indications are very poor (about half of WCD achievement), e.g. in terms of \(R^2\) value. Overall, by compromising the performance and the computational cost, by using the same metamodel design criteria, the proposed approach provides more generalised approximation for air quality modelling.

The surface graphs of the test function and the corresponding error functions using different DOE methods are shown in Fig. 4. The spatially distributed ozone results are obtained for one test day over full cell grids of the domain (i.e. \(N_{\text{full}}=3500\) cells). Ideally, the surface graphs of the errors should be flat and near zero. The surface graph of the error function based on the WCD sampling method shows minimal errors when compared with the other two methods. More fluctuated points appear at the left region (i.e. in the west area of Sydney) by using \(n\)-level FFD and LHD methods.

**CONCLUSION**

A new method for the sampling design for a neural network metamodel has been presented in this paper. The validity and reliability of the proposed approach has been evaluated in several ways. By using the radial basis function neural network metamodel, the performance of proposed approach was compared with two well-known sampling design strategies; the \(n\)-level full factorial design and the Latin hypercube design. First, a known non-linear test function, namely, The Hock–Schittkowski Problem 100 was used in the evaluation to validate the effectiveness of the proposed scheme. Next, it has been applied to the air quality problem for the estimation of spatial distribution of the ozone concentration. Using historical meteorological data collected at Sydney’s monitoring sites with calibrated input-output dataset from a photochemical dispersion model, the proposed metamodel is capable of predicting the spatially distributed ozone concentration in the interest domain with a fair accuracy. It is also noted that the proposed sampling method outperforms the other two evaluated methods in terms the
network size and the simulation time, for both the test problem and the air quality modelling application.

References
Evaluation of various visualization forms for facility operation and maintenance

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Purpose Ongoing case studies in different facility settings revealed that current industry solutions (such as BAS and CMMS) still lack the capability to enable users to understand and interpret raw data for operation efficiency as well as plan for maintenance tasks in complex facilities efficiently. There is still a need for facility operators to put data into spatial or knowledge context and make decisions for actions during operation and maintenance (OM). Visualization is a promising aid to provide intuitive support for facility personnel while dealing with complex spatial data and large amount of raw/processed data and to enable them to respond promptly to issues that arise. This research focuses on identifying visualization requirements for facility personnel, evaluating various visualization forms for supporting OM-decisions and developing a formal approach to supporting visualization requirements. Method Two case studies and shadowing work are still ongoing in two different types of facilities (one is in a complex campus building, the other one is in a highly-sensed conservatory). The purpose of these studies is to identify the inefficiencies or difficulties associated with the lack of visualization support in current OM-practice. We have identified an initial set of visualization requirements from these studies and analyzed different scientific visualization forms (e.g. 2D, 3D, desktop virtual environment, and immersive virtual environment) as well as information visualization forms (e.g. color/pattern coding, text/number overlay, graph, etc.) used in human computer interaction and architectural engineering construction and FM (facility management) domain through extensive literature review. We developed a matrix of initial set of visualization requirements for different OM-tasks and visualization platforms to understand characteristics of visualization support requirements. Results & Discussion This paper provides an initial set of visualization requirements for typical tasks identified from the two case studies and a synthesis of extensive literature review on scientific and information visualization platforms that exist in the current body of knowledge. The mapping of the initial set of requirements to visualization platforms reveals that OM-work efficiency can be improved by multiple visualization forms, and the characteristics observed from this mapping can be used as a basis for a formal approach to identify applicable visualization platforms for a given task from the OM-domain.

Keywords: information technology, facility operation and maintenance, visualization

INTRODUCTION

Modern buildings, especially large scale public buildings, are usually equipped with Building Automation Systems (BASs) to help facility managers to deal with large amounts of sensor data generated during operation and take automated action for control. Usually, there is a typical control strategy selected based on a given season/setting and BAS runs under this strategy. However, BAS cannot respond to changes in the physical environment that are not measured by sensors and programmed in the control logic. We call these physical settings as information requirements related to external parameters and define them as factors that will influence building operation monitoring and control strategy but are not captured by BAS.

Exploratory studies that we have done with operators revealed that external parameters are indispensable for effective building operations, and facility operators need to understand the external parameters and their changes in relation to internal parameters being monitored. On one hand, facility operators need to interpret the sensor readings provided from BAS under the effect of external parameters and see if the control strategy in the BAS is still valid or not. For example, under a given spatial setting, facility operators would ignore the temperature reading fluctuations of a certain sensor since s/he knows that the sensor is installed near roof vents and the fluctuation is due to the status of the roof vents (being open or close). Without knowing the physical proximity of the sensors to the control equipment (i.e., the roof vent in this example) and the status of the control equipment, the fluctuations would be misunderstood and would result in unnecessary actions such as sensor recalibration or equipment's over-running. Similarly, facility operators’ intervention for equipment control (equipment referred to as HVAC equipment in this paper) is necessary when changes in the environment are beyond the sensing capabilities of sensors or not reflected in the control strategy. For example, when a laboratory is under renovation, facility operators should shut off the air supply valve.
to stop the supply to that room. Facility operators need to be aware of the changes in this external parameter (i.e., space being renovated) and adjust the temperature requirement in the laboratory accordingly. In large scale or complex facilities, it's difficult for human to keep up with all kinds of internal/external parameters and their changes to figure out if the sensor readings are meaningful or any equipment needs to be adjusted. Current industry solutions for BASs still lack the capability to provide intuitive interface about such internal/external parameters and enable users to understand sensor data as well as manipulating control equipment efficiently. Hence, there is a need for interpreting the internal parameters captured and monitored by BAS under the influence of the external parameters and making wise decisions accordingly.

Visualization is able to provide intuitive support for facility operators while dealing with complex spatial data and large amounts of parameters being monitored; however visualization techniques have not been fully leveraged in the domain. Visualization is divided into two high-level categories as scientific visualization and information visualization. The former typically refers to visual representation of physically based objects, such as buildings, human body, components in a building, for full cognition, while the latter focuses on data or information which is non-physically based, such as semantic information about building components and sensor readings, and targets on providing visual representation of such concepts to improve human knowledge and capability to identify trends or patterns.

This paper provides an overview and initial results of two ongoing case studies for identifying what internal/external parameters operators consider when they interact with BAS and their visualization requirements, and proposes an initial discussion of visualization techniques that can be leveraged to display such requirements in an effective way. The case studies are ongoing for the last 5 months and involve shadowing and interviews with facility operators working in two different facility settings. The scenarios, workflows, difficulties or inefficiencies of facility operators’ interactions with BAS in their daily routine were captured, documented and synthesized. The next section provides the need for combining internal parameters with external parameters visually and discusses the problems in the current practice in visualizing this information.

**THE NEED FOR VISUALIZING MONITORED DATA IN PHYSICAL SETTINGS AND THE PROBLEMS IN THE CURRENT PRACTICE**

Exploratory studies have been done in a highly-sensed conservatory and a large scale campus with the objective of identifying facility operator’s information and visualization requirements. The conservatory has 35 rooms or zones where many types of plants, having different temperature and humidity requirements, are grown. The plants are delicate and indoor environment needs to be monitored and controlled strictly. The campus represents the large scale case with more than 100 buildings with complex HVAC systems. Initially, we investigated the user interfaces of the BASs that the facility operators are using, referred to as BAS1 and BAS2. The investigation of BAS1 interface of the conservatory showed that it lists sensor readings for temperature and humidity in zones and thresholds in a tabular format as shown in Figure 1. There are 16 sensors tabulated in this interface without any color coding. It’s difficult for facility operators to identify which readings in which zones are beyond thresholds promptly so that they can figure out if BAS is working properly or if manual intervention is necessary. The BAS2 interface in the campus is able to show sensor reading status by visualization of color coding in floor plans, as shown in Figure 2 for a specific building in the campus.

**Fig. 1. BAS interface showing sensor reading/threshold and equipment status in the conservatory**

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**Fig. 2. BAS interface showing sensor reading status and equipment status in a specific campus building**

Generally speaking BAS2 is better than BAS1 in terms of providing more intuitive interface by leveraging a scientific visualization technique, a floor plan, and information visualization techniques such as
color coding and text overlay. However, both of them lack functions of providing external parameters that are required by facility operators. For example, precise sensor location along with the control equipment location to figure out sensor proximities to equipment (such as sensors being close to vents) is not possible to be captured from the two BAS interfaces and thus it relies on the familiarity of the operator with the physical space.

Equipment control has similar problems. The user interfaces through which facility operators input control command for both buildings contain tables, which list the IDs of the equipment and their statuses and working parameters. Whenever, a facility operator wants to manipulate a certain equipment (e.g., close a vent to protect the plants that are nearby the vents), s/he has to look at the annotated floor plan s/he prepared with control equipment IDs marked on it and find the ID of the specific vent s/he wanted to close and then matched it to the IDs in the user interface. It was also observed that after the facility operator manually changes equipment control parameters, a follow-up visit to the site is needed to make sure the right equipment was manipulated; if it is the wrong one, s/he has to go back to the main office to re-input command and revisit the site. In addition to that, facility operators typically want to leave the control of equipment to BAS. In cases when control equipment is manually overridden, for example, manually shutting off the equipment which is under maintenance, facility operators would like to keep track of which equipment is on manual mode and their current status (e.g., a valve being open or close, or the percentage of opening) in an effective way. The current way of tracking such large amounts of information in the tabular format is not intuitive for people to get insights in a short time when the number of control equipment is large. This at times results in facility operator not identifying which equipment needed to be turned to automated mode or not remembering which the equipment was in manual mode. This is especially problematic when there is day and night shifts for monitoring and different people are responsible for different shifts. Equipment that is under manual mode should be identified at a quick look when shifts occur.

We also grouped the information items captured by BAS, defined as internal parameters, and additional information that are required by facility operators to do their tasks but not captured by BAS, defined as external parameters. Table 1 shows the list of internal parameters, and the current way of displaying this information to facility operators. BAS cannot respond to these internal parameters correctly with respect to sensor and equipment’s external parameters such as their spatial context. Table 1 also shows an initial set of external parameters that we identified from exploratory studies and needed by facility operators to interpret the internal parameters. Also, majority of internal and external parameters to be interpreted together require this information embedded in the physical setting (integration of scientific and in-

<table>
<thead>
<tr>
<th>Information displayed (internal parameters)</th>
<th>Displayed on BAS interface?</th>
<th>Current display form</th>
<th>Problems of current display forms</th>
<th>Visualization category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, sunlight intensity and direction</td>
<td>Both BAS1 and BAS2</td>
<td>Text</td>
<td>N/A</td>
<td>Information Visualization</td>
</tr>
<tr>
<td>Sensor readings measuring room temperature and humidity</td>
<td>BAS1</td>
<td>Tabular format</td>
<td>Hard to interpret when there is a long list of sensors and control equipment</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Sensor thresholds of room temperature and humidity</td>
<td>BAS2</td>
<td>Color-coded floor plan</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Equipment’s working/control status and working parameters, such as water/air supply/return temperature, air flow rates, etc.</td>
<td>BAS2</td>
<td>Text overlay on equipment pictures</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Sensor reading status measuring rooms’ temperature (current readings compared with thresholds)</td>
<td>BAS2</td>
<td>Color-coded floor plan</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Equipment’s working/control status and working parameters such as water/air supply/return temperature, air flow rates, etc.</td>
<td>BAS2</td>
<td>Text overlay on equipment pictures</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
</tbody>
</table>

Table 1. Information displayed to operators through BAS interface and the current way of visualization

<table>
<thead>
<tr>
<th>An example set of external parameters required to be visualized with internal parameters</th>
<th>Displayed on BAS interface?</th>
<th>Current display form</th>
<th>Problems of current display forms</th>
<th>Visualization category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content location and requirements</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Equipment location with respect to spatial layout and content requirements</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Sensor location with respect to spatial layout and equipment locations</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Equipment’s maintenance status with respect to content requirements</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
<tr>
<td>Sensor’s maintenance status with respect to content requirements</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>Integration of Scientific and Information Visualization</td>
</tr>
</tbody>
</table>
In the current practice, it is left to facility operators to bring this information together in mind and visualize under the physical context of the facility.

In summary, these exploratory studies showed that current industry solutions are not able to provide sufficient visualization support for facility operators when they need to do interaction with BAS. Thus, in order to improve the efficiency of facility monitoring and control, integration of scientific visualization and information visualization is needed.

**REVIEW OF SCIENTIFIC AND INFORMATION VISUALIZATION TECHNIQUES IN AEC/FM AND HCI DOMAIN**

In order to understand what visualization techniques that exist in current body of knowledge can be leveraged for facility operators during monitoring and control tasks, we examined the previous research studies on visualization in Architecture Engineering Construction and Facility Management (AEC/FM) and Human Computer Interaction (HCI) domains. In the AEC/FM domain, physically and non-physically based information is closely related. For example, a Gantt chart, showing non-physically based information about the construction processes are actually related to building elements (physical objects). Thus, we see that many visualization related research works in the AEC/FM domain contain integration of scientific and information visualization techniques, with applications ranging from construction simulation/monitoring and facility operation. There are studies in the HCI domain that look at embedding non-physically based information in 3D virtual world, with the purpose of helping user build the link between perceptual environment and the related abstract information. Previous studies on the integration of scientific and information visualization from both AEC/FM and HCI domains provide various visualization techniques of displaying non-physical based information in physical based environment, such as color coding, text overlay, icon, or graph. In addition, multi-views in coordination with the primary visualization can provide more detailed information by separated window. Various techniques of integrating scientific and information visualization are different in terms of their capabilities of visualizing various data type, information priority and supporting different analysis purposes. For example, color coding is very intuitive and easy to grasp user’s attention, thus it is appropriate to visually represent information with high priority, but the limitation is that color coding cannot show high-dimensional data. The various visualization techniques need to be analyzed and evaluated in order to match their capabilities with visualization requirements for facility operators.

**AN INITIAL SET OF VISUALIZATION REQUIREMENTS OF FACILITY OPERATORS IDENTIFIED FROM CASE STUDIES**

The purpose of the case studies is to identify (a) the patterns of facility operators’ interactions with BAS during sensor data interpretation and equipment control manipulation, at different scales, (b) what internal and external parameters they consider during these tasks and (c) inefficiencies or difficulties associated with insufficient visualization support in their interaction process. The major differences in the two case settings are that the operators in the campus are responsible for multiple buildings which have different load conditions, while the conservatory requires delicate content to be monitored and it has unique requirements to be met in multiple zones.

Various instances of sensor data interpretation and manual overriding of control equipment were observed throughout the research period, where internal and external parameters would need to be considered together for decision making. These instances are synthesized together to categorize what parameters are needed for facility operators and summarized in Table 2. Internal and external parameters or their changes can be categorized under four categories: (a) outdoor environment related, which are defined as outside weather and time related factors, such as outside air temperature, light intensity and direction. (b) indoor environment related, which are defined as indoor special layout, space characteristics (e.g., room type, glass wall location, room temperature requirement, etc.) and content related factors; (c) equipment status related, which are defined as equipment’s status properties, such as equipment working status (e.g., open/close), maintenance status (e.g. working properly or waiting for repair) and control status (e.g. auto/manual); (d) sensor status related, which are defined as sensor’s status properties, such as sensor maintenance status. What worth mentioning is that some internal parameters’ changes still require facility operator’s manual intervention even though they are captured by BAS, because no programmed logic was created to respond to the specific case.

The examples identified from case studies, which involve facility operator’s manual actions or decision-makings triggered by different internal/external parameters or their changes, are listed in Table 2. Table 2 also provides what external and internal parameters operators consider in each example and what needs to be visualized for the operators. We categorized these identified examples based on their visualization requirements. The examples show different patterns in terms of what combination of parameters should be considered for visualization, shown as below:
Visualization that requires equipment + indoor and outdoor environment related parameters

This visualization requirement necessitates equipment related parameters to be visualized in relation to indoor and outdoor environment. Visualization requirement incorporates control equipment’s locations, status properties, and indoor and outdoor environment related parameters such as content requirements and space requirement changes so that facility operator can react to these parameter changes promptly by manipulate the correct equipment in a spatial context.

Example 1: In the conservatory case for instance, when the outdoor environment changes – temperature is lower than 50 °F, facility operator will manually overwrite control command of the side-wall vents (equipment related) near tropical plants (indoor environment related) to “Manual close 100%”, to prevent those plants from constant cold air.

Example 2: In the conservatory case, the facility operator has to overwrite the control command of a shade curtain (equipment related) to “Manual close 100%” to protect a certain type of tree nearby (content, indoor environment related) which is sensitive to strong sunlight.

Example 3: In the campus case, when a laboratory is under renovation (indoor environment related), facility operators will shut off the air supply valve (equipment related) to stop cooling supply feeding that room.

Visualization that requires indoor environment + sensor related parameters

This visualization requirement necessitates internal parameters of sensor’s reading and threshold, external sensor related parameters – sensor location and sensor working/maintenance status, to be integrated with indoor environment related parameters, such as space characteristics or content requirement, so that operators can interpret sensor reading under spatial context correctly.

Example 4: In the conservatory case, sensors (sensor related) located near glass walls (indoor environment related) have the chances being exposed in hot spot under direct sunlight, and it leads to higher temperature reading, which will be interpreted as normal when strong sunlight is against glass wall and BAS’s cooling behavior will be stopped manually.

Example 5: In the campus case, facility operators will pay attention to sensor readings which have frequent or sharp fluctuation (sensor related). If the sensor is installed in a classroom with varied occupancy status (indoor environment related), fluctuations will be interpreted as normal thus no need for recalibration.

Example 6: In the conservatory case whenever gardener waters plants, sensor (sensor related) near the plants (indoor environment related) will have extremely high humidity reading resulting sharp fluctuations, which will also be interpreted as normal and eliminate redundant working of dehumidifier.

Table 2 External and internal parameters to be visualized and examples from case studies

<table>
<thead>
<tr>
<th>Internal parameters/Change in internal parameters</th>
<th>Examples of facility operator’s decisions/actions triggered by the parameters or parameter changes</th>
<th>What needs to be visualized?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor environment related</td>
<td>Example 1: Keep the vents near tropical plants close manually when outside air temperature &lt; 50 °F</td>
<td>Equipment + Indoor and Outdoor environment parameters</td>
</tr>
<tr>
<td>Sunlight intensity and direction</td>
<td>Example 4: Interpret high temperature reading as normal when sensor near glass wall is in hotspot</td>
<td>Indoor environment + Sensor parameters</td>
</tr>
<tr>
<td>Equipment status related</td>
<td>Example 7: Interpret low temperature reading as normal when vents near sensor is open for dehumidifying</td>
<td>Sensor + Equipment + Indoor parameters</td>
</tr>
<tr>
<td>Control status</td>
<td>Example 10: Switch control model to automatic when specific occasion lapses</td>
<td>Equipment parameters</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>External parameters/Change in external parameters</th>
<th>Examples of facility operator’s decisions/actions triggered by the parameters or parameter changes</th>
<th>What needs to be visualized?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor environment related</td>
<td>Example 3: Shut off air supply valve to the room which is under renovation</td>
<td>Equipment + Indoor environment parameters</td>
</tr>
<tr>
<td>Space usage type</td>
<td>Example 5: Interpret temperature fluctuation in classroom as normal</td>
<td>Indoor environment + Sensor parameters</td>
</tr>
<tr>
<td>Content requirement change</td>
<td>Example 2: Manual open curtain to protect a certain tree nearby which is sensitive to sunlight</td>
<td>Equipment + Indoor environment parameters</td>
</tr>
<tr>
<td>Equipment status related</td>
<td>Example 6: Interpret high humidity reading as normal when sensor locates near plants being watered</td>
<td>Indoor environment + Sensor parameters</td>
</tr>
<tr>
<td>Maintenance status</td>
<td>Example 8: Keep roof vent close manually when it is waiting for maintenance; Example 9: Stop the chiller whose motor is malfunctioning</td>
<td>Equipment parameters</td>
</tr>
<tr>
<td>Sensor status related</td>
<td>Sensor readings are unreliable when network or sensor is malfunctioning</td>
<td>Sensor parameters</td>
</tr>
</tbody>
</table>
Visualization that requires sensor + equipment + indoor related parameters

This visualization requirement necessitates bringing sensors’ and equipment’s location with respect to special layout (indoor environment related), and their status properties together, so that facility operator can better understand sensor readings, equipment’s behavior and their relationship in spatial layout, in order to prevent misunderstanding of sensor reading and unnecessary equipment operation.

Example 7: In the conservatory case, sensors (sensor related) located near roof vents (equipment related) in the tropical forest (indoor environment related) will have lower than normal temperature readings when vents are open for dehumidifying, which will be interpreted as all right considering the opening of vents.

Visualization that requires equipment related parameters

This visualization requirement necessitates highlighting equipment related parameters, control equipment’s unusual status, such as under maintenance or manual control mode. With this information, facility operators will have less chance to mistakenly open broken equipment or forget to switch manual control equipment back to automatic promptly.

Example 8: In the conservatory case, facility operator overwrites the control command of a row of roof vents to “Manual close” because s/he knows the motor of that specific row of vents was broken and is waiting for repair.

Example 9: In the campus case, the facility operator manually stops one chiller because the chiller motor is malfunctioning and is waiting for maintenance.

Example 10: In the conservatory case, the facility operator overwrites control command of a row of vents to “Manual open” for maintenance purposes but forgets to switch the control mode back to automatic before he is off work on Friday, which resulted in cancelation of an important event scheduled for that weekend because rain fell inside through the open roof vents.

CONCLUSION

Two ongoing case studies on operation monitoring and control in different facility settings reveal the fact that physical setting is indispensable when facility operators interpret sensor readings and manipulate control equipment. The initial set of parameters that influence facility operator’s decision-making identified from the case studies can be grouped into four categories: outdoor environment related; indoor environment related; equipment status related and sensor status related. Examples of facility operator’s manual interaction triggered by different internal/external parameters or their changes are analyzed, and the external and internal parameters operators consider in each example and what needs to be visualized for the operators is identified. Detailed analysis of current information display forms of the identified visualization requirements showed that current practice still lacks the functions of bringing external and internal parameters needed by facility operators in an intuitive way. Visualization, with the capabilities of helping human to deal with complex spatial information and large volumes of abstract data effectively, is a promising aid to improve the efficiency and effectiveness of facility operators’ sensor data interpretation and equipment manipulation. The information and visualization requirements show that facility operation requires both spatial information and semantic information, thus needs the integration of scientific visualization and information visualization. Further works need to be done to evaluate capabilities of various visualization techniques for supporting facility operator’s decisions and then the capability evaluation can be used as the basis for a formal approach to identify applicable visualization techniques for a given task from facility operation domain.

References


Integrated approach for older adult friendly home staircase design

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2 Faculty of Nursing, Alberta University, Alberta, Canada
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Purpose The concept of designing or modifying home environments plays an important role in maintaining safety for older adults (65 and older). Poor staircase architectural design could contribute to increasing the risk of falling for older adults. The purpose of this research is to evaluate staircase architectural design by investigating the risk of falling associated with staircase elements and aiming to improve the surrounding environment for older adults living independently in their homes. This paper presents research which is built around the following hypotheses: ‘Improving the architectural design of staircase could reduce the risk of falling for older adults’. Method This research provides an integrated evidence-based assessment that combines all aspects related to staircase architectural design, represented in the following 3 stages. Stage 1 constructs a hierarchy of four elements which represent the architectural design of the staircase as follows: (i) staircase geometrical design; (ii) handrail design; (iii) lighting; and (iv) step design. Each element is divided to a number of features; for instance, handrail design, if exists, is divided into five features: (i) handrail height; (ii) handrail cross-section; (iii) handrail surface texture; (iv) handrail extension; and (v) minimum handrail-wall clearance. Each feature is divided into a number of scenarios representing the different architectural design alternatives for that feature: e.g., variation on handrail heights. A rating factor that represents the degree by which the proposed scenario reduces the risk of falling for older adult, is assigned to each scenario. Stage 2 develops a rating system for the analyzing staircase elements and features which present the degree to which each element and its features reduce the risk of falling for older adults. In this stage, a mathematical model is developed to calculate the rating value for different staircase design scenarios. Stage 3 develops a decision tree analysis module called a design assessment tree (DAT) which represents a complete vision for different staircase design scenarios. A case study is presented in order to illustrate the effectiveness of the proposed methodology. Results & Discussion The result of the developed rating system is a rating number for different staircase design scenarios that represent the degree by which the proposed staircase architectural design reduces the risk of falling for older adults. Figure 1 illustrates the optimal design scenario for the geometrical design element, which is part of the developed DAT for the staircase assessment procedure. DAT works as a manual for architects to represent the staircase assessment for any proposed design, and to visualize the optimal design scenario comparing to other scenarios in the each branch.

Keywords: staircase design, older adult, risk of falling

INTRODUCTION

Ascending and descending staircases have been reported as a difficult daily activity for older adults1. Statistically, one out of four older adults is expected to fall when climbing staircases in the home environment2. Falling for older adults might lead to injuries3,4. In addition to experiencing physical harm, older adults might experience loss of confidence or develop a fear of falling, which will impact their performance while ascending or descending staircases1,3,4,5,6.

There is a wide variation of staircase configurations such as spiral staircases, straight staircases with landing, and U-shaped staircases. Each staircase configuration has been associated with different handrailing, lighting and step dimensions (riser and tread). The concept of modifying staircase configuration plays an important role in maintaining safety for older adults. Previous studies have investigated the cause of falling through ascending or descending staircases for older adults3,4,5,6,9. Other studies have recommended staircase modifications for handrail, lighting and step design to reduce the risk of falling5,10,16.

This paper presents an evidence-based integrated framework that combines all aspects related to staircase architectural design to reduce the risk of falls in older people. A practical case study of staircase design is presented from the perspective of reducing the risk of falling for older adults to demonstrate the effectiveness of the proposed methodology. First, the staircase is divided into a number of elements that represent its architectural design. Then, those elements are divided into a number of features that provide more detailed specifications. Each feature has different scenarios that represent the architectural design alternatives for that feature. A rating factor is calculated for each element and its associated features to represent how much it reduces the
risk of falling for older adults based on previous evidence-based studies. The proposed methodology assesses the staircase design, while not the actual value or true meaning of the rating numbers presented. Design Assessment Tree (DAT) has been developed to represent a complete vision of different staircase design scenarios. DAT could work as a manual for architects to represent the staircase assessment for any proposed design, and to visualize the optimal design scenario compared to other scenarios in each branch.

STAIRCASE ELEMENTS AND FEATURES
The staircase is divided into four design elements: staircase geometrical design, handrail design, lighting, and step design elements. This categorization follows the logical divisions provided in the building code. Handrail, lighting and step specifications are provided in the building code as subdivisions of the staircase design specifications. In addition, staircase geometric design is considered to be a design element that presents the formation of the staircase as an independent design object, which can only be tracked by the geometrical design of the staircase. The staircase geometrical design element is divided into the staircase configuration and the number of steps per flight, represented as two subdivision features. Each element is divided into a number of features that define its architectural design, as illustrated in Figure 1.

PROPOSED RATING SYSTEM
The developed rating system represents the degree by which the risk of falling for older adults is reduced. A rating factor (R) is assigned to different alternatives (scenarios). This rating factor is calculated based on an evidence-based comparison with alternative scenarios.

To set the comparison, a scale of numbers between 0.00 and 1.00 has been adopted to indicate how much each scenario may reduce the risk of falling for older adults. The rating factor 1.00 represents optimal risk reduction; the scaled numbers from 1.00 to 0.00 represents the scaled reduction of the risk of falling for older adults, as illustrated in Table 1. The rating factor 0.0 means that the feature does not exist. For example, if the handrail does not exist, the rating factor of the “handrail existing” feature will be 0.00.

<table>
<thead>
<tr>
<th>Rating Factor</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>The risk of falling for older adults is optimally reduced by the selected scenario (Optimal design feature)</td>
</tr>
<tr>
<td>0.75</td>
<td>The risk of falling for older adults is strongly reduced by the selected scenario (Strong design feature)</td>
</tr>
<tr>
<td>0.50</td>
<td>The risk of falling for older adults is moderately reduced by the selected scenario (Moderate design feature)</td>
</tr>
<tr>
<td>0.25</td>
<td>The risk of falling for older adults is increased by the selected scenario (Weak design feature)</td>
</tr>
<tr>
<td>0.00</td>
<td>The design feature does not exist (Highest risk of falling)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEMENT 1: STAIRCASE GEOMETRICAL DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the perspective of investigating the risk of falling for older adults, staircase configuration and length of each flight of the staircase are two important factors. Therefore, staircase geometrical design, as an element, can be divided into two main features that specify its architectural design: 1) staircase configuration which represents variation in staircase shapes (straight, circular or composite); and 2) number of steps per flight.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feature 1: staircase configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>This paper covers a wide range of staircase configurations including: 1) U-shape staircases; 2) Quarter turn staircases; 3) Straight staircases with landing; 4) Straight staircases without landing; 5) Helical staircases; 6) Spiral staircases; and 7) Composite staircases, illustrated in Figure 2, arranged from highest to lowest risk reduction in terms of falling for older adults. The optimal staircase design has been found</td>
</tr>
</tbody>
</table>
to be the U-shaped staircase design\textsuperscript{18, 20}, which has an associated rating factor of 1.00.

The composite staircase is defined as a mixed staircase configuration in one staircase connecting two floors. The worst staircase configuration is the composite staircase, as it causes an irregular gait pattern which increases the risk of falling for older adults\textsuperscript{10, 18, 19, 21}. The composite staircase has an associated rating factor of 0.20. The remaining staircase configurations have a range of rating factors according to how much each staircase configuration reduces the risk of falling for older adults.

\textbf{ELEMENT 2: HANDRAIL DESIGN}

The handrail is an essential tool that assists older adults’ movement while ascending and descending staircases\textsuperscript{22}. Handrail design consists of six features: handrail existence, handrail height, handrail cross-section, handrail surface texture, handrail extension, and minimum handrail-wall clearance. These six features are chosen to represent the handrail design specifications that have been found to reduce the risk of falling for older adults. To express importance of each scenario compared to others, a suitable rating factor is assigned to each of the scenarios according to the potential reduction in the risk of falling for older adults.

\textbf{Feature 1: handrail existence}

Evidence suggests that as a person ages, the need for a handrail increases. Safety in ascending and descending a staircase is further enhanced when a handrail exists on both sides of the staircase\textsuperscript{11, 22}. The scenarios for “handrail existence” are: 1) to have one handrail on each side of the staircase, which is the optimal design scenario with a rating factor of 1.00; 2) to have one handrail on one side of the staircase, which has an associated rating factor of 0.7 as a moderate case; and 3) to have no handrail on either side of the staircase with a rating factor of 0.00 as the feature does not exist.

\textbf{Feature 2: handrail height}

Handrail height is the vertical line from the top of the rail to the outside edge of the staircase, as illustrated in Figure 3(a). There are four scenarios for the “handrail height” feature\textsuperscript{15, 18}: 1) handrail height \( \leq 910 \) as the optimal design scenario with a rating factor of 1.00; 2) handrail height \( \leq 970 \), which is considered the optimal handrail height, as it is the most preferred height by older adult users\textsuperscript{15}, and has an associated rating factor of 0.7 as a moderate case; 3) handrail height \( \geq 1,000 \), both of these cases are the worst case scenarios with a rating factor of 0.4 as lower than moderate design; and 4) handrail height \( \geq 1,000 \), which is neither the optimal nor the worst case with an associated rating factor of 0.7 as an over moderate design.

Fig. 2. Staircase geometrical design: staircase configuration

\textbf{Feature 2: number of steps per flight}

Long flights (over 12 steps) or short flights (less than 6 steps) have been found to increase the risk falling\textsuperscript{12, 13, 18}. There are four scenarios for the “number of steps per flight” feature: 1) \( \leq 10 \) number of steps per flight \( \leq 12 \), which is the optimal case and has an associated rating factor of 1.00; 2) \( 7 \leq \text{number of steps per flight} < 10 \), which is an over moderate case with an assigned rating factor of 0.6; 3) number of steps per flight \( \leq 6 \); and 4) number of steps per flight \( \geq 12 \) which has the worst case scenarios with an associated rating factor of 0.25 indicating that they highly increase the risk of falling for older adults.
Feature 3: handrail cross-section

By facilitating handrail graspability, the risk of falling could be reduced\(^\text{(14)}\). To facilitate graspability of the handrail a suitable handrail cross-section should be selected\(^\text{(14)}\). The “handrail cross-section” feature is considered to be a function of the handrail shape and the handrail cross-section dimension\(^\text{(14, 19)}\). The optimal scenario, based on the ability to grasp the handrail, is to have a circular handrail cross-section with a circumference between 100-mm (32-mm diameter) and 160-mm (51-mm diameter), or to have an oval handrail cross-section with dimension of 50-mm in height and 37-mm in width\(^\text{(14)}\). These two scenarios have an associated rating factor of 1.00 representing the optimal case of the handrail cross-section. Other handrail shapes and dimensions are rated as over moderate designs as they have been found to have lower level of comfortability in most cases\(^\text{(14)}\).

Feature 4: handrail surface texture

In order to facilitate handrail graspability, the surface texture needs to be not too smooth or not too rough\(^\text{(14, 18)}\). This case is considered as the first scenario of the “handrail surface texture” feature, and rated as 1.00 to represent the optimal scenario. The second scenario is to have too smooth handrail surface texture or too rough handrail surface texture. In that case the associated rating factor is 0.25 as it highly increases the risk of falling\(^\text{(14, 18)}\).

Feature 5: handrail extension

Handrail extension, as illustrated in Figure 3(b), at the top and bottom of staircases has been found to be important in assessing older adult movement when ascending or descending the staircases\(^\text{(11)}\). There are four scenarios for the dimension of the “handrail extension” feature\(^\text{(5)}\): 1) 320 ≤ handrail extension on at least one handrail ≤ 480, which is the optimal scenario and has an associated rating of 1.00; 2) handrail extension on at least one handrail > 480, which is lower than the optimal case scenario with an associated rating factor of 0.8; 3) no handrail extension, which is associated with a rating factor of 0.5 as it moderately increases the risk of falling for older adults; and 4) handrail extension on at least one handrail ≤ 320 is the worst scenario as it has been found that a short handrail extension increases the risk of falling more than no handrail extension\(^\text{(11)}\), thus the associated rating factor is 0.4.

Feature 6: minimum handrail-wall clearance

The purpose of investigating the minimum handrail-wall clearance, illustrated in Figure 3(b), is to provide a sufficient space to grasp the handrail in case of a falling emergency. There are four scenarios for the “min handrail-wall clearance” feature\(^\text{(18, 23)}\): 1) a smooth wall surface and handrail-wall clearance ≥ 57-mm; and 2) a rough wall surface and handrail-wall clearance ≥ 75-mm, both of these cases are the optimal cases which have a rating factor of 1.00; 3) a smooth wall surface and handrail-wall clearance < 57-mm; and 4) a rough wall surface and handrail-wall clearance < 75-mm, these two cases are the worst scenarios as they increase the risk of having finger injuries while moving the hand on the handrail and increase the risk of falling when ascending or descending the staircase\(^\text{(11)}\), and thus have a rating factor of 0.4 indicating a lower than moderate design.

Element 3: Lighting

Poor vision is associated with increasing the risk of falling for older adults on staircases as they often require an increased lighting level\(^\text{(24, 25)}\). The lighting element is divided into three features that specify: 1) illumination level; 2) consistency of lighting; 3) light switch types and locations.

Feature 1: illumination level

Lighting for older adults has been recommended by Illuminating Engineering Society of North America-IESNA to be a minimum of 300-lux throughout the entire staircase\(^\text{(24)}\). The “Illumination level” feature is divided into two scenarios: 1) illumination level ≥ 300-lux, which is the optimal scenario and has an associated rating factor of 1.00; and 2) illumination level ≤ 300-lux, which is the worst scenario and has an associated rating factor of 0.4.

Feature 2: consistency of lighting

Providing consistent lighting throughout the entire staircase is a very important factor that contributes to reducing the risk of falling for older adults\(^\text{(18, 24)}\). Providing inconsistent lighting may cause shaded areas on staircases which could cause confusion and might result in falls\(^\text{(18, 24)}\). Two scenarios are provided for the “consistency of lighting” feature: 1) consistent staircase lighting, which is the optimal scenario and has an associated rating factor of 1.00; 2) inconsistent staircase lighting, which is the worst...
Feature 3: light switch types and locations
In order to reduce the risk of falling, light switches need to be placed away from the staircase path and should be two-way \cite{16,19}. Four scenarios are provided for the “light switches” feature. The first scenario is light switch away from staircase path and two-way light switch, which is the optimal case and has an associated rating factor of 1.00. The second and third scenarios are: 1) light switch through staircase path and two-way light switch, and 2) light switch away from staircase path and one-way light switch, both scenarios are slightly over the moderate case with an associated rating factor of 0.6. The last scenario is light switch through staircase path and one-way light switch, which is the worst case with an associated rating factor of 0.4.

Element 4: step design
The step design element considers step design specifications, which are: 1) going depth; riser height; nosing shape and dimensions; and step finishing material (see Figure 4). In this paper, the selected step design specification is based on the most preferred step dimensions provided in previous evidence-based studies for different age groups, including older adults \cite{16,18}.

Feature 1: going depth
The going depth represents the depth of the tread without nosing (see Figure 4). For the “minimum going depth dimension” feature, there are three scenarios \cite{16,18}: 1) \(280 \leq \text{going depth} \leq 330\), which is the optimal scenario and has an associated rating factor of 1.00; 2) going depths \(280\); and 3) going depth \(\geq 330\). The latter two scenarios are the worst case and have an associated rating factor of 0.4.

Feature 2: riser height
Three scenarios are provided for the “minimum riser height dimension” feature \cite{16,18}: 1) \(152\) riser height dimension \(\leq 190\) which is the optimal scenario and has an associated rating factor of 1.00; 2) riser height dimension \(\geq 152\); and 3) riser height dimension \(\geq 190\). The latter two scenarios are the worst case and have an associated rating factor of 0.4.

Feature 3: nosing
Safer staircase design can be achieved by optimizing the staircase nosing \cite{18,26}. The optimal scenario for the “nosing design” feature is to be rounded with nosing depth between 15-mm and 25-mm \cite{16,26}. The worst case scenario is not to be rounded with nosing depth outside of the range of the optimal scenario. The worst case has an associated rating factor of 0.25 as it is highly associated with increasing the risk of falling for older adults \cite{26}. Intermediate cases such as satisfying the optimal nosing dimension, but not satisfying the optimal shape also have intermediate rating factors.

Feature 4: step finishing material
Finishing step material represents the texture, pattern and color of the finishing material of each staircase step. The optimal case scenario for the “finishing step material” feature is to have cohesive finishing material with uniform slip-resistance for the staircase steps \cite{16,26}, which has an associated rating factor of 1.00. The worst case scenario is to have non-cohesive finishing material and non-uniform slip-resistance for staircase steps. In this case, the associated rating factor is assigned to be 0.4.

Assessment calculations
One scenario is selected to represent the proposed staircase design. Based on the rating factor (R) that is assigned to each scenario for each feature, an average rating factor (\(\bar{R}(Y)\)) is calculated for each element, representing the selected scenario of each feature. This average rating factor represents how much the proposed features for each element reduces the risk of falling for older adults. The average rating factor must satisfy Equation 1.

\[
\bar{R}(Y) = \frac{\sum R(X)}{n}
\]

(1)

Where:
- \(\bar{R}(Y)\) = average rating factor (\(\bar{R}\)) for element Y;
- \(R(X)\) = rating factor (R) for feature X;
- Y = index for element symbol;
- X = index for feature symbol; and
- n = the total number of features for element Y (n=2 for staircase geometrical design (G), n=6 for handrail design element (H), n=3 for lighting element (L), and n=4 for step design element (S)).
A rating number (N) is generated to represent and rank the importance of each of the four elements. The summation of the four rating numbers is 100. This paper proposes an equal rating number (N) for the four staircase elements (25 each). The corrected rating number \( N_c(Y) \) is calculated by multiplying the rating number by the average rating factor of each element, which represents how much each element, relative to the other elements, reduces the risk of falling for older adults. The corrected rating number \( N_c(Y) \) for each of the four elements must satisfy Equation 2.

\[
N_c(Y) = \overline{R}(Y) N(Y) \tag{2}
\]

Where:

\( N_c(Y) = \) corrected rating number for element Y;
\( \overline{R}(Y) = \) average rating factor (\( R(Y) \)) for element Y;
\( N(Y) = \) rating number (N) for design element Y;
\( Y \) = index for element symbol.

The summation of the four corrected rating numbers represents how much the proposed staircase design reduces the risk of falling for older adults. Thus, in the perfect hypothetical case, the staircase rating must equal 100. The total rating for staircase design is calculated satisfying Equation 3.

\[
N_{\text{total}} = \sum N_c(X) \tag{3}
\]

Where:

\( N_{\text{total}} = \) total rating number of the proposed staircase architectural design;
\( N_c(X) = \) corrected rating number for staircase element (X).

A scale is developed to categorize the total rating of the staircase from the perspective of reducing the risk of falling for older adults. A total rating from (100 to 90) represents the optimal staircase design; (90 to 65) represents strong staircase design; (65 to 40) represents moderate staircase design; (40 to 15) represents a weak staircase design; and (15 to 0) represents the staircase design associated with the highest risk of falling.

**DESIGN ASSESSMENT TREE (DAT)**

The Design Assessment Tree (DAT) is a decision tree that has only decision nodes. DAT works as a manual for architects to represent a complete vision for staircase assessment for any proposed design. In addition, DAT allows the architect to visualize the optimal design scenario compared to other scenarios in each branch. Each individual branch in the DAT carries the rating factor (R) of each scenario. There are two columns at the end of each DAT branch, as illustrated in Figure 5: the first column lists the average rating factor for each design scenario, calculated by satisfying Equation 1; the second column displays the corrected rating number \( N_c(Y) \) for each design scenario, calculated by satisfying Equation 2. DAT is developed for each element independently.

**CASE EXAMPLE**

Fig. 6. Perspective/plan: straight staircases w/o landing

To illustrate the effectiveness of the proposed staircase assessment, the case example of straight staircase without landing is presented, as shown in Figure 6. The proposed staircase consists of 16 steps per flight; with a handrail height of 900-mm and it exists in one side of the staircase. The handrail cross-section shape is rectangular with smoothed edges. The illumination level = 250-lux and the lighting throughout the staircase is consistent. The light switch is away from the staircase path and is a two-way switch. Tables 2, 3, 4 and 5 illustrate the actual scenarios for each feature based on the proposed staircase design, and provide the associated rating factors.

**Table 2. Features of staircase geometrical design**

<table>
<thead>
<tr>
<th>Feature no</th>
<th>Feature’s name</th>
<th>Proposed scenario</th>
<th>Rating factor (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature 1</td>
<td>Staircase configuration</td>
<td>Straight cases without landing</td>
<td>0.4</td>
</tr>
<tr>
<td>Feature 2</td>
<td>Step no/flight (G_s=16 steps)</td>
<td>(G_s=16 steps) ≥ 12</td>
<td>0.25</td>
</tr>
</tbody>
</table>
### Table 3. Features of handrail design

<table>
<thead>
<tr>
<th>Feature No</th>
<th>Feature's name</th>
<th>Proposed scenario</th>
<th>Rating factor (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature 1</td>
<td>Handrail existence</td>
<td>One handrail</td>
<td>0.7</td>
</tr>
<tr>
<td>Feature 2</td>
<td>Handrail height</td>
<td>(Hh = 900) ≤ 910-mm</td>
<td>0.4</td>
</tr>
<tr>
<td>Feature 3</td>
<td>Handrail cross-section</td>
<td>Other handrail shapes and dimensions</td>
<td>0.7</td>
</tr>
<tr>
<td>Feature 4</td>
<td>Handrail surface texture</td>
<td>Comfortable handrail surface texture (not too smooth or not too rough)</td>
<td>1</td>
</tr>
<tr>
<td>Feature 5</td>
<td>Handrail extension</td>
<td>No handrail extension</td>
<td>0.5</td>
</tr>
<tr>
<td>Feature 6</td>
<td>Minimum Handrail-wall clearance</td>
<td>Smooth wall surface and handrail-wall clearance 57-mm</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4. Features of lighting

<table>
<thead>
<tr>
<th>Feature No</th>
<th>Feature's name</th>
<th>Proposed scenario</th>
<th>Rating factor (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature 1</td>
<td>Illumination level</td>
<td>(Li=250-lux) ≤ 300-lux</td>
<td>0.4</td>
</tr>
<tr>
<td>Feature 2</td>
<td>Consistency lighting amount</td>
<td>Lighting throughout staircases is consistent</td>
<td>1</td>
</tr>
<tr>
<td>Feature 3</td>
<td>Light switches</td>
<td>Light switch away from staircases path and two-way light switch</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 5. Features of step design

<table>
<thead>
<tr>
<th>Feature No</th>
<th>Feature's name</th>
<th>Proposed scenario</th>
<th>Rating factor (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature 1</td>
<td>Going depth</td>
<td>(Sg=269-mm) ≤ 280-mm</td>
<td>0.4</td>
</tr>
<tr>
<td>Feature 2</td>
<td>Riser height</td>
<td>152 ≤ Sr = 174-mm ≤ 190-mm</td>
<td>1</td>
</tr>
<tr>
<td>Feature 3</td>
<td>Nosing</td>
<td>(Nosing dimension=40-mm) ≤ 25-mm and not rounded</td>
<td>0.5</td>
</tr>
<tr>
<td>Feature 4</td>
<td>Step finishing material</td>
<td>Finish material provide evened throughout the stairs and provide uniform slip-resistance</td>
<td>1</td>
</tr>
</tbody>
</table>

The average rating factor (\( \bar{R} \)) for the staircase geometrical design element (G), handrail design (H), lighting (L), and step design (S) is calculated satisfying Equation 1 as follows:

\[
\bar{R}(G) = \frac{(0.4 + 0.25)\times 2}{2} = 0.325 \\
\bar{R}(H) = \frac{(0.7 + 0.4 + 0.7 + 1 + 0.5 + 1)\times 6}{6} = 0.72 \\
\bar{R}(L) = \frac{(0.4 + 1 + 1)\times 3}{3} = 0.8 \\
\bar{R}(S) = \frac{(0.4 + 1 + 0.5 + 1)\times 4}{4} = 0.725 \\
\]

The corrected rating number for the staircase geometrical design element (G) handrail design (H), lighting (L), and step design (S) is calculated satisfying Equation 2 as follows:

\[
N_g(G) = \bar{R}(G) N(G) = 0.325 \times 25 = 8.13 \\
N_g(H) = \bar{R}(H) N(H) = 0.72 \times 25 = 18 \\
N_g(L) = \bar{R}(L) N(L) = 0.8 \times 25 = 20 \\
N_g(S) = \bar{R}(S) N(S) = 0.725 \times 25 = 18.13 \\
\]

The total rating for the proposed straight staircase without landing is obtained by satisfying Equation 3. The total rating for the proposed staircase design (64.26) indicates that the proposed straight staircase without landing has a moderate staircase design.

\[
N_{total} = 8.13 + 18 + 20 + 18.13 = 64.26 \\
\]

The same results can be obtained by selecting DAT branches that express the proposed scenarios. The total rating of the staircase can be optimized by selecting better scenarios for different design features from the developed DAT. For example, as illustrated in Figure 6, the number of steps per flight can be optimized by selecting the optimal scenario, with an associated rating factor of 1.00, which is to have between 10 to 12 steps per flight. Also, the effect of choosing a certain scenario on the average rating factor (\( \bar{R} \)) can be tracked. Therefore, the architect might decide to add a landing in the middle of the staircase to satisfy the optimal number of steps per flight; in that case, the average rating factor will be optimized from 0.33 to 0.7. This process can be applied to different features of the four elements to optimize the whole staircase design. The advantage of using DAT for optimization is that rating factor for the different scenarios of each feature are visually easier to extract and compare.

![Fig. 6. scenarios for number of steps per flight and its associated rating factors](image-url)
CONCLUSION
This paper proposes an integrated assessment for staircase architectural design which aims to reduce the risk of falling for older adults. The assessment considers all the features of staircase design that could be improved through different scenarios. The assessment has been developed by evidence-based analysis of the staircase elements (staircase geometrical design, handrail design, lighting, step design). The proposed integrated staircase rating system enables architects to assess the proposed staircase design with the aim of reducing the risk of falling for older adults. Additionally, the developed integrated staircase rating system and DAT can be used as a design tool to improve staircase design through choosing alternative scenarios for different design features. A case example is analyzed to demonstrate the use of the proposed staircase assessment.

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Efficacy of different insole designs on fall prevention of the elderly

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3 FootDisc Inc, Taipei, Taiwan

* Corresponding author (swyang@ym.edu.tw)

Purpose Between 28 to 35% of people aged over 65 fall in a year; for those aged over 70 the falling rate is as high as 32 to 42%. Many factors may lead to a fall, and these risk factors can be categorized as either endogenous or exogenous. Propriocepton biofeedback and ankle strategy are one of the basic control mechanism to keep posture balance and prevent falling. The purpose of this study was to evaluate different hardness and arch support designs in controlling the posture stability.

Method A group of fifteen 'fallers', i.e fall-experienced elderly, (average age 67.7±2.4 years) and eighteen non-faller elderly (average age 68.7±3.1 years) were recruited for this study. The elderly were subjected to an exhaustive examination which included collecting demographic data, a proprioceptive test, a functional balance test, a Berg-balance test, as well as a dynamic balance assessment system tested with the eye open or closed (Biodex Medical System, Inc., USA) with a pressure mat (Xsensor X3, Canada) on top of the platform. Four types of orthotic insoles (Performace, Proactive, and Hardboot from Footdisc®, and Power step from Dr. Kong). The insoles each had different arch support hardness used to support ankle stability during ankle rocker motion, and cushions at metatarsal heel regions used to protect sensitive foot structure against strain and proprioception. During each test, foot pressure and the center of pressure (CoP) were recorded and analyzed. Statistical analysis was performance using SPSS v17.0 software.

Results & Discussion The faller group showed significant larger CoP excursion particularly in the medio-lateral direction, as well as the anterior-posterior mean CoP velocity with the eye opened. In the test with eye closed, the CoP trajectory increased profoundly, although the faller group was larger than the non-fallers, but this was not significant. The increased of medio-lateral (ML) sway implies an increased fall risk; poor vision elevated the falling rate. With orthotics, the sway trajectory reduced, among that the Proactive insole (arch height 1.75cm) showed the best posture stability control. It reduced the ML-excursion with an average of 29% for non-fallers and 35% for fallers, respectively.

Keywords: fall risk, orthotics, posture control

INTRODUCTION
Falls are the most common and lethal accident that occur in the elderly. There are approximately 28-35% of people aged 65 and over each year; with age increased to 70, the falling rate reaches 32-42%1. However, older community-dwelling women experience significantly more falls than do older men2. Many factors result in falling; these risks can be categorized either endogenous or exogenous. Falls are leading causes of traumatic accidents and reducing physical activities for the elderly3. Aging is associated with changes in function of sensory and musculoskeletal system which contributes to postural stability. Postural stability has been defined as the control of the body’s position in space for the purposes of balance and orientation. However, poor balance, or postural stability, is significant predictors the risk of fall in the elderly4. Postural movement patterns include three discrete control strategies: hip, knee, and ankle strategy5. The ankle rocker is an important factor to maintain balance during standing and the ankle strategy restores the center of mass (CoM) to a position of stability through body movement4. Propriocepton biofeedback and ankle strategy are one of basic control mechanism to keep posture balance and prevent from falling5,6. According to the age-related change, the elderly who are loss of ankle joint flexibility5 and reduce the proprioceptive acuity at the foot may be associated with functional impairment, predisposing older adults to falls1. Foot and ankle conditions in older adults are associated with mobility and balance impairment, disability, falls, and fracture9. The planter aponeurosis plays a fundamental role in foot biomechanical mechanism during standing. As the foot transmitted the load of body weight, its longitudinal arches become length and flatten. Otherwise, the interaction of the plantar aponeurosis with skeleton of the foot is a major component of arch stability in the foot10. Foot orthoses with arch support are generally believed to align the skeleton and to maintain it curved posture to decrease plantar aponeurosis strain10. And Arch support orthosis can help to stabilize the bone structure and then produce standing stability. Moreover, arch support insole also increases ankle rocker stability. In addition, effective control of foot motion and
ankle stability may decrease postural sway and the risk of fall in the elderly. The purpose of this study was to evaluate how the different hardness and arch support designs in controlling the posture stability.

**METHOD**

Fifteen fall-experienced elderly (67.67±2.40 y/o) and eighteen non-faller elderly (68.67±3.13 y/o) were recruited in this study. The elderly were subjected to an exhaustive examination including the collection of demographic data, proprioceptive test, static balance test (double stance, single leg stance, tandem stance), Berg balance scale (BBS), as well as a dynamic balance assessment system tested in eye opened or closed conditions (Biodex Medical System, Inc., USA) with a pressure mat (Xsensor X3, Canada) on top of the platform. The experimental procedure flow chart was shown in Fig 1. Four types of orthotic insoles (named Performance, Proactive, and Hardboot from Footdisc®, and Power step from Dr. Kong) (Fig. 2). The insole had different arch support hardness used to support ankle stability during ankle rocker motion, and cushions at metatarsal/ heel regions used to protect sensitive foot structure against its strain and proprioception. During each test, foot pressure and the center of pressure (CoP) were recorded and analyzed. Statistical analysis was performance using SPSS v. 17.0 software.

**RESULTS & DISCUSSION**

The demographic data was shown in Table 1, there were no significant for the test subjects. The range of motion and foot function were no difference between two groups except the fall-experienced (faller) had larger forefoot varus (Table 2). In the static balance test, it showed significant high score in single stance and tandem stance test (Table 3). During dynamic balance tests, the faller group showed significant larger maximal CoP excursion particularly in the medial-lateral direction (Fig. 3), as well as the anterior-posterior mean CoP velocity in the condition of eye open (Fig. 4). In the condition of eye closed test, the CoP trajectory increased profoundly, although the faller group was larger than non-faller but was not significant. The increased of M-L sway implies the increase of fall risk, the poor vision condition elevated the falling rate. With orthoses, the sway trajectory reduced, among that the Proactive insole (arch height 1.75 cm) showed the best posture stability control. It reduced the M/L of CoP excursion with average of 29% for non-fall and 35% for faller, respectively (Fig. 5). As a result, we found the elderly with arch support insoles improved M/L of CoP excursion and increased postural stability, since the arch support the midfoot bones lock each other to provide foot stability during ankle rocker, and the insole material also promotes the proprioception.

**CONCLUSION**

The assessment of postural control systems in recurrent fallers was essential to design the prevention measures needed to minimize physical consequenc-es of falls in the elderly. The CoP measures during dynamic perturbation were able to explain the variance of postural stability between the faller and non-faller elderly. Smaller maximal CoP trajectories in M/L direction were found in the non-faller elderly than the faller group. Of the four insoles and barefoot tested, the Footdisc® Proactive insoles (arch height 1.75 cm) had stable longitudinal arch support and heel criddle mechanisms that significantly reduced postural sway. Therefore, for the reasons discussed above, these results indicated the insoles, such as Footdisc® Proactive insoles, had the control capabilities of dynamic postural stability on fall prevention of the elderly.

---

*Fig. 1. The experiment flow chart*  
*Fig. 2. Tested orthotic insoles*
Fig. 3. Maximal CoP excursion in the medial-lateral direction between the faller and non-faller elderly in the condition of eye open

Table 1. Demographic data of subjects

<table>
<thead>
<tr>
<th></th>
<th>Non-faller elderly</th>
<th>Faller elderly</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>18</td>
<td>15</td>
<td>0.223</td>
</tr>
<tr>
<td>Age(y/o)</td>
<td>67.67 ± 2.40</td>
<td>68.87 ± 3.13</td>
<td></td>
</tr>
<tr>
<td>Body height</td>
<td>156.03 ± 4.38</td>
<td>156.13 ± 6.17</td>
<td>0.955</td>
</tr>
<tr>
<td>Body weight</td>
<td>56.33 ± 6.99</td>
<td>58.33 ± 8.39</td>
<td>0.459</td>
</tr>
<tr>
<td>BMI</td>
<td>23.17 ± 3.01</td>
<td>24.04 ± 3.99</td>
<td>0.480</td>
</tr>
<tr>
<td>Foot length</td>
<td>23.34 ± 0.79</td>
<td>23.64 ± 1.03</td>
<td>0.359</td>
</tr>
<tr>
<td>Foot width</td>
<td>8.36 ± 0.72</td>
<td>8.79 ± 0.97</td>
<td>0.166</td>
</tr>
</tbody>
</table>

Table 2. Foot function evaluation

<table>
<thead>
<tr>
<th></th>
<th>Non-faller elderly</th>
<th>Faller elderly</th>
<th>Non-faller elderly</th>
<th>Faller Elderly</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexion</td>
<td>22.56 ± 4.34</td>
<td>22.53 ± 4.67</td>
<td>0.989</td>
<td>23.44 ± 4.37</td>
<td>0.625</td>
</tr>
<tr>
<td>Plantarflexion</td>
<td>36.39 ± 3.96</td>
<td>37.93 ± 3.39</td>
<td>0.243</td>
<td>36.56 ± 3.60</td>
<td>0.169</td>
</tr>
<tr>
<td>Eversion</td>
<td>7.61 ± 1.38</td>
<td>8.33 ± 2.36</td>
<td>0.285</td>
<td>7.59 ± 1.29</td>
<td>0.267</td>
</tr>
<tr>
<td>Inversion</td>
<td>15.22 ± 1.86</td>
<td>15.67 ± 2.69</td>
<td>0.580</td>
<td>16.27 ± 2.09</td>
<td>0.539</td>
</tr>
<tr>
<td>Tibial Torsion</td>
<td>9.22 ± 2.09</td>
<td>8.33 ± 2.38</td>
<td>0.348</td>
<td>9.50 ± 2.99</td>
<td>0.275</td>
</tr>
<tr>
<td>Forefoot angle</td>
<td>-3.28 ± 0.75</td>
<td>-1.93 ± 2.58</td>
<td>0.069</td>
<td>-1.73 ± 2.81</td>
<td>0.018*</td>
</tr>
<tr>
<td>Rearfoot angle</td>
<td>2.34 ± 0.64</td>
<td>2.36 ± 0.62</td>
<td>0.275</td>
<td>2.33 ± 1.36</td>
<td>0.026*</td>
</tr>
</tbody>
</table>

Table 3. Balance Score from Biodex system

<table>
<thead>
<tr>
<th></th>
<th>Non-faller elderly</th>
<th>Faller elderly</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBS</td>
<td>55.17 ± 1.098</td>
<td>53.93 ± 2.314</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>1.58 ± 0.51</td>
<td>3.29 ± 0.97</td>
<td>0.275</td>
</tr>
<tr>
<td></td>
<td>2.29 ± 0.62</td>
<td>4.54 ± 1.30</td>
<td>0.015*</td>
</tr>
<tr>
<td></td>
<td>2.43 ± 0.71</td>
<td>4.73 ± 1.14</td>
<td>0.044*</td>
</tr>
<tr>
<td></td>
<td>1.48 ± 0.42</td>
<td>3.36 ± 1.17</td>
<td>0.002*</td>
</tr>
</tbody>
</table>
References


Gait rehabilitation with a robotic dog

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Purpose Gait rehabilitation is a fundamental requirement to avoid disuse syndrome for the long-term hospitalized person such as cerebral infarction patient or patient with dementia. In general gait rehabilitation is monotonous and dull, so some entertainment or a sense of achievement is helpful to maintain motivation during the daily exercise. This paper proposes an effective gait-rehabilitation system using a robotic dog supporting individual initiatives of the patient.

Method Walking with a living dog is one way to achieve this; however as an intervention it is limited to mildly symptomatic patients because a real dog risks sudden lunging. We used a robotic dog instead of a living dog for relatively critical patients. We have studied robot-assisted activity and therapy using robotic animals in the elderly nursing home in order to improve residents’ quality of life (QOL). In the case of a man-made robot, aforementioned risks can be ignored. Moreover, it is an advantage that an in-house walking exercise with the dog is possible. The basic concept of this proposal is co-creation of steps between the elderly and dog. That is, the real-time stabilometric signal of the elderly was measured and analyzed to extract a single step and forwarded to the robotic dog to make a step. Since commercially available amusement products pass through the safety review of public administration, the proposed system was composed of those products as a hardware tool. More specifically, entertainment robot AIBO of Sony ERC was adopted as the robotic dog and Nintendo’s Wii-balance-board is used as the stabilometric human interface devices. All signals are transmitted by conventional Bluetooth and LAN systems.

Results & Discussion Figure 2 shows the block diagram and enforcement scenes of gaiting exercise at standing and sitting positions, respectively. The patients both suffered from dementia and made their own steps in a positive manner shown by arrows in the figure. Such positive attitude was uncommon in the conventional daily exercise. Functions for walking back and forth walk, and turning right and left are installed. It is noteworthy that the standing patient tempts the dog to move toward another patient and the patient calls the robot to her. This means there a co-creation field is created through the robotic dog. This was followed by a chat between the patients. In the case of the sitting patient, although for her it is very hard exercise to raise her foot from the floor, she made several steps on her own initiative successively after the physical therapist guided her how to walk by patting and lifting her right and left knees alternately. The position of the center of gravity and command signal were logged every 0.1 sec in the control PC and available to be analyzed afterward. For example, the change of exhaustion during exercise was estimated from the magnitude and regularity of steps. Since all hardware tools can be packed in a suitcase the proposed gait exercise can be easily done everywhere.

Keywords: robotics, rehabilitation, nursing, dementia, gait, co-creation, therapy

INTRODUCTION Interaction between a robot and an aged person produces effects in three domains, physical, mental, and social. In relation to the physical domain, industrial robot technologies are being applied to provide practical equipment that assists walking, bathing, and other daily physical activities, but research on the application of robotics in relation to the metal and social domains has been more limited. Recently, however, robot-assisted activity/therapy has been receiving considerable attention in all three domains¹⁴. While animal-assisted activity/therapy has a long history and much research has been accumulated on its utility and effectiveness, it has some limitations. We have been conducting studies on robot-assisted activity from the viewpoint of overcoming the limitations by replacing the animal with a robot⁵. These limitations arise from the fact that the animal is a living creature and therefore poses problems of infection, feeding and excretion, and needing a handler. In addition, we must be mindful of animal abuse. All of these problems can be solved when the animal is replaced with a robot. One of the issues being focused on in robotics research is how to make the robot show elements of a living creature. In this paper, we discuss how the use of an animal robot can induce aged persons to complete monotonous walking exercise. The important aspect of the proposed approach to walking rehabilitation is that the aged persons control the robots independently.

MERITS OF USERS CONTROLLING AN ANIMAL ROBOT FOR WALKING REHABILITATION Aged persons staying in nursing homes or hospitals over the long term are at risk of serious accidents
such as falls due to decline in physical functioning. To help prevent this, residential facilities offer a variety of physical exercises to augment the medical treatments the residents receive. Simple standing and walking are among the most basic and effective of these exercises. A number of positive effects can be expected if residents are able to walk around the home or hospital: it expands their active range, which in turn improves their sociality, an important factor for aged residents who can readily spend time on their own. Walking exercise is therefore of crucial importance. However, such exercise becomes a chore if there is little sense of purpose for it.

Most aged persons have some experience of walking a living dog. Even for those without physically impairment, walking a dog brings health benefits such as prevention of metabolic syndrome. It can be difficult and even dangerous, however, for patients who are largely housebound due to functional deterioration to try to walk outdoors with a living dog. In particular, patients with loss of motor function following cerebral infarction have to begin with very basic exercise like taking one step at a time when walking. Such walking exercise is monotonous and hard work, and residential facilities are concerned about how to motivate residents to continue exercising. If walking exercise could be made entertaining, the residents’ attitude toward exercise could be changed from a passive to active one. As an example, Figure 1 shows the robot walking game called the “AIBO Derby” that uses Sony Corporation’s robotic dog AIBO. The robot is equipped with a program to chase a pink-colored object. Four AIBOs are lined up at the start line, as in a horse race, and they “run” on a course prepared on a table-tennis table toward their ‘owners’. The users hold and show a pink-colored ball to their own AIBO so that their AIBO walks faster toward them. Competing in the race leads to positive feelings among the participants and most of them are unconsciously doing physical exercise through standing, holding the ball, and waving the ball as a stimulus. In this exercise, in addition to producing the desired physical effects, the residents’ sociality will also be improved through mutual communication during the game.

**CONFIGURATION OF THE PROPOSED SYSTEM**

**Outline of the system**

The proposed system is composed of three hardware components: the human interface device (HID), the control server computer, and the robot. All of the hardware devices can be transported in a medium-sized suitcase. The HID senses the resident’s physical action and sends data to the server. The server computer analyzes the data and converts it to a control command which is then sent to the robot. The control command activates the robot’s actions that are programmed and installed in the body of the robot in advance. A block diagram of the system is shown in Fig. 2. In order to keep spatial freedom and safety, all electric data signals are transmitted through wireless links and all of the devices are driven by a battery to avoid accidents involving electric cables. We used commercially available hardware devices when creating the entire system for the following reasons. First, the devices already on the market have passed a public safety review so they can be used in public spaces such as hospitals and nursing homes for the elderly. Also, commercially available amusement tools are ergonomically sophisticated and are a comfortable fit for aged persons. Second, just the distribution of the software allows therapists to quickly and easily try the robot-assisted therapy in their work setting at a moderate price. This is important because as awareness of robot-assisted activity/therapy is much lower than that of animal-assisted activity/therapy, we need to encourage therapists to try it and see its effectiveness for themselves.

**Human interface device**

We adopted the operation terminal of a TV game supplied by Nintendo as the HID. The HID needed to have functions that aged persons could operate easily to control the robot. Two types of HID were selected for use. The first type is the hand-held acceleration sensing HID called the “Wii remote controller”, shown in the top left of Fig. 2. This HID was selected for users who can walk unassisted.

![Fig. 1 The “AIBO Derby” game using AIBO robotic dogs](image)
The user can send a signal to make the robotic dog walk simply by swinging the device and then follows the robot on foot when it starts to walk. The HID, which can be fixed to a waist belt, can also move the robot forward by acceleration of the moving trunk when tuned to a higher sensitivity.

The second type of HID used was the "Wii Balance Board", shown in the upper center of Fig. 2. This HID was selected for users who have difficulty standing and walking by themselves. This HID is a kind of stabilometer and is equipped with four load sensors, one at each corner of the board. The user makes the robotic dog walk by simply making steps on the board. The relationship between the user’s single step and robot’s single step can be tuned by the control program.

Control server
The HID device and the control server are connected by a Bluetooth wireless system (2.4GHz, 1Mbps). The specs for a conventional PC are sufficient for the control server. A netbook type PC with touch panel operation, in this case the Fujitsu FMV-LOOX series, was used.

When using the first type of HID, the handheld HID, the control server analyzes the acceleration strength detected by the HID and sends a walk command to the robot when it exceeds the preliminarily given threshold. The robotic dog then walks a certain number of steps. The threshold value and the number of steps can be set up through the server console.

When using the second type of HID, the balance board HID, every 100 ms the server program calculates the coordinate value of the position of the center of gravity based on the data from the four load sensors in the board. It determines whether the user is sending a signal for the robot to make a step or not from the user’s change in the position of the center of gravity. In detail, just after the board is switched on and before loading, the four sensors are calibrated so that the center of gravity lies at the center of the board. A step is considered made when the center of gravity passes over a virtual vertical threshold line that lies at the right or left center of the board, under the condition that the center of gravity remains for a certain period in the right or left region of the board before crossing over. This condition is in place to avoid a crossing error caused by noise signals. In addition, there are special areas configured to send signals to turn the robot right and left: a right (left) command is generated if the center of gravity stays in the right (left) front area of the board.

For users who cannot maintain a standing position with the balance board HID, a mode with much higher sensitivity is available, called the "on-chair" mode. Both the standing and on-chair modes have heavy, medium, and light exercise settings, enabling the user to select from six difficulty levels of exercise. The position of the center of gravity is displayed on the console screen in-situ as a real-time position or as a locus. These selections are all made on the server console, named the “AIBOard” (Fig. 3). All temporal data including the center of gravity and induced commands are automatically saved every 100 ms into a log file that can be analyzed later.

Fig. 3 Control console, the “AIBOard”

Robotic dog
The AIBO ERS-200 series and ERS-7 series supplied by Sony Corporation were used as the robotic dog. AIBO ERS210 and ERS-7 are shown in the top and bottom right of Fig. 2, respectively. These robots were chosen from those available on the market because they are equipped with wireless LAN hardware and an IP address can be assigned, and the robot’s basic behavior can be programmed by the user using the supplied programming platform. This enables the user to control the robot’s motion, such as back and forth steps and right and left turns, based on the commands transmitted from the server. A dog lead can be connected to the robotic dog to help promote the walking exercise if preferred.

Operation procedure
The devices are switched on and the wireless connection is confirmed on the server console. The IP address of the AIBO is then input so that the data communication channel from the HID to the AIBO is kept logically active. The time needed for this procedure is 5 min at most. When using the balance board as the HID, the AIBO waits in the sitting position with no load on the board, then stands up and waits when the user places weight on the board.

RESULTS
Operation with the handheld HID
The proposed system was used in a nursing home for the elderly, as shown in Fig. 4. It was observed that an ambulant user followed the robotic dog that he controlled through simple swinging of the HID. The user who had mild dementia also talked with
nursing staff about a dog that he used to feed in the past. In this instance, the original purpose of the proposed system was achieved as the robotic dog prompted the user to walk voluntarily around the home. It became clear, however, that since the walking rate of the AIBO is rather slow, when using the handheld HID effectiveness would be limited to users who have major difficulty in walking unassisted.

**Operation with the balance board HID**

Walking exercise using the balance board HID is suitable for users who cannot walk without an assistive device. The user makes steps on the board placed within a walking frame (Fig. 5). The recorded loci of the center of gravity for a younger, healthy male user (90 kg body weight) and for an aged user (45 kg body weight) are shown in Fig. 6. The loci correspond to position recorded every 100 ms and lines connect the positions. For the case of the younger user, clear weight shifts can be seen to the right upper and left upper quadrants to turn the robot and normal shifts between the right and left sides of the board enabled the AIBO to walk straight ahead. For the aged user, however, the weight shift was insufficient to complete turns of the robot and making the robot walk continuously in a straight line by weight shifting from right to left was clearly very difficult.

One of the problems associated with using stepping on the balance board HID to operate the system is that the user cannot move forward in the same way as in normal walking. Figure 7 compares the loci of two aged users, A and B, with similar body weight. The range of B’s forward and backward weight shifts is obviously larger than A’s while the right-to-left weight shifts are similar for both users. Figure 8 shows weight shifts occurring over a 1-min period (taken from Fig. 7) for users A (blue line) and B (red line). User B moves slightly forward over time and returns to the original position several times whereas user A maintains relatively stable stepping.

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*Fig. 4 Walking exercise using the handy HID*

*Fig. 5 Walking exercise using the board HID*

*Fig. 6 Loci of the center of gravity*

*Top: younger, healthy male user, Bottom: aged user*

*Fig. 7 Loci of the center of gravity for aged users A and B*
The typical right-to-left weight shift over a 1-s period is shown in Fig. 9. The moment a step occurs is defined as the time when the center of gravity passes over the center threshold line (red circle). Figure 10 shows the change in stepping rate over a 4-min period. Stepping begins with a slow repetition rate of 1.4 s, then becomes stable from about 1s and becomes disordered around midway through the period.

Simultaneously recorded video images show that the user initially took rhythmic and stable steps elevating the foot, but this elevation gradually reduced and weight shift was then made by moving the trunk toward the right and left.

**DISCUSSION**

Most participants in this preliminary study to examine the possibilities of the proposed system had dementia with a score on the Hasegawa Dementia Scale-Revised (HDS-R) ranging from 5 to 25 (30 = healthy, 0 = severe dementia). The system, which enables users to control the robot by swinging the hand or making steps, appeared to be useful with these participants. The proposed walking exercise would also be useful for rehabilitation of spatial configuration recognition. On the balance board, the users remain in a fixed location while the robot moves and points in various directions. To turn the robot in the chosen direction, the user has to construct the virtual spatial configuration that includes both the robotic dog and himself. When both parties are pointing in the same direction, it is relatively easy to make the robot turn because the direction of the robot and user coincide. This is identical to the case using the handheld HID when the user swings it and follows the robot. When the user is facing the robot it becomes more difficult to make the robot turn because right for the robot corresponds to left for the user. The user must recognize this and make the necessary movement in order for the robot to turn correctly.

The demand for the proposed walking exercise system was strong among the participants who could not maintain a standing position. The trial for one of these participants is shown in Fig. 11. The user sits on the chair and makes a step on the board. The weight of just the leg itself can be used in this instance to operate the robot, as opposed to the whole body weight being used by users in the standing position. For seated users it is necessary to increase the sensitivity of the load sensors and to reduce the noise to avoid malfunction. As shown in
Fig. 11, the robot could be operated from the chair by stepping after tuning of the stepping decision algorithm.

It was seen in this study that although most patients did not view the robotic dog as a living creature, their voluntary behavior was still induced. It seems that they viewed the robot as machine-like but not a real machine, which would be due to the phenomenon of embodiment that comes from the robots dog-like appearance and its animal-like behavior. As evidence to support this, users often addressed the robot directly and voluntarily. Although animal-assisted activity using living animals shows promise for improving the quality of life of aged persons, it still requires a handler to be present during rehabilitation exercises for aged persons with physical and cognitive impairment. Robots are able to compensate for this limitation and also can likely maintain quality of life when used complementarily with animals.

CONCLUSION

Walking rehabilitation exercise using the robotic dog AIBO was proposed. The entire system including the HID was prepared from commercially available products. The preliminary trial showed possibilities for its use with aged persons with quite severe physical and cognitive decline and shows promise to assist in their rehabilitation.

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References

A generic method for the assessment of smart walkers

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Purpose This paper presents a generic method to assess the usability of smart-walkers. With an increasing number of assistive robots available, it is important to make sure they work before making a choice. Mechatronic systems propose more functions that are of interest to the ageing frail or handicapped population than conventional walking frames. For example: helping the user to get up or to sit down, avoiding obstacles, finding directions, driving, etc. These systems are all research prototypes, except PAM-AID which was marketed under GUIDO™. Most of them were tested in order to validate their features either with healthy young subjects, or with elderly people. However, only PAMAID was tried for its usability. In that study the PAM-AID was compared to the AMD (Assistive Mobility Device developed by Atlanta VAMC which is totally passive and without sensors) and the user’s usual walking aid. The test used in the evaluation protocol is a 36.6m course, without obstacles, with each of the three different technical devices. The time to complete the test and a questionnaire were included in the analysis. Our reports suggest that a generic method is needed to evaluate smart-walkers whatever their robotics features.

Method The usability of smartwalkers was assessed with a normalized test used in geriatric medicine to diagnose frailty and walking difficulties: the 4-meter walking test. If the volunteer failed to complete the 4 meters, the protocol specified the test would stop at that stage. Failure of the 4-meter test was defined as taking over ten times more time to complete the test with a device than it would take volunteer walking usually (i.e. without aid or a different aid such as a cane). During the test, the volunteer was first trained to complete the test, then to complete it with first the regular walking frame and then again with the robuWalker. Training lasted as long as the volunteer wanted to feel sufficiently confident. Each test was run immediately after training with a new device (usual way of walking; walking frame; robuWalker). The method adds to the time of completion a gait analysis including the feet motion extracted from videos. Results & Discussion In a previous article we analyzed the completion time. However time is hardly sufficient to describe the required speed of an active smart walker, extra information such as trajectory, instant speed, distance to the marking, duration of double limb, etc. are also required. We applied to the 4m-test a gait analysis including feet motion analysis from the videos of our two groups of four healthy elderly volunteers and four impaired volunteers (with both motor and cognitive impairments) and three test conditions.

Keywords: elderly people, walking aids, robots, Geriatric assessment, method

INTRODUCTION

The increasing number of elderly people in our society, also ageing is most commonly successful, is causing an increase in the need for useful assistive devices. An effective walking aid (or walker) has to answer several criteria: be usable, efficient, stabilizing and of low energy cost to the user. These criteria are strongly linked. A pathological walk will be more expensive in terms of energy and a fall will have a greater risk to occur. Regular walking frames are rudimentary, they don’t provide obstacle avoidance, can’t help to stand securely from seated. The ideal device should supply a mechanical support and should be able to adapt itself to the environment and to the incapacities of the user. A robotic device is in practice most likely to be able to answer these specifications. Previous works have proposed smart-walkers addressing these needs.

Mechatronic systems allow additional functions such as:
- helping the user to get up or to sit down,
- to avoid an obstacle,
- to help in orientation,
- driving, etc…

The existing systems can be classified according to their features. A motorized smart-walker can work on two modes: passive or active. When it is passive; it is following the movements of the user, in this case the human is the master over the system. When it is active; it can move by itself and override, to some extent, the intentions of the user, in particular to avoid an obstacle. Both modes (passive or active) can use the same mechatronic system depending on the choice of various control modes on the motorized wheels. However, some systems are only passive¹, or with active brakes only² or active in direction only³,⁴. Most of the smart-walkers
have motorized wheels, allowing an active assistance in weight support and in direction. Some are mobile robots fitted with handles placed in front of the user\textsuperscript{5,6}, but the majority of the systems have the same configuration as the regular four-wheeled walkers. The motorized wheels take place at the back when they are fixed in direction\textsuperscript{7} so as to place the instantaneous center of rotation closer to the user, and indifferently at the back or in front if they are omniwheels\textsuperscript{8}.

In all cases the pull and direction of the smart walker are controlled according to a treatment of the efforts of interaction between the handles and the user’s hands\textsuperscript{9,10,11}. Most of them have an obstacle detection function. But few of them can help in Sit-To-Stand\textsuperscript{12,13}.

These systems are all research prototypes, except PAM-AID which was marketed under GUIDO\textsuperscript{14}. Most of them were tested in order to validate their features either on healthy adult subjects, or on the elderly\textsuperscript{16,17}. Only PAM-AID was tried on its usability\textsuperscript{18}. In that study the PAM-AID was compared to the AMD (Assistive Mobility Device designed by Atlanta VAMC is totally passive and without sensors) and the user’s usual walking aid. The test used in the evaluation protocol is a 36,6m course, without obstacle, with the three technical devices. The time to complete the tests and a questionnaire were used in the analysis.

This paper is proposing a method to assess the efficiency of smart-walkers. We compare the use of a standard walking frame by four healthy senior volunteers and four elderly patients with some level of motor and cognitive impairment. We are comparing the efficiency of the walkers using the time of task completion and the fit between the human and the walker according to markers on the recorded videos.

**MATERIAL AND METHOD**

RobuWALKER (rW) was developed in DOMEO project (AAL-2008-1-159), to be assessed with prospect-users.

**Protocol of experiments**

The protocol presented here is part of the objective to estimate the main technological profits expected from the project. The assessment of the use of the technical aid is made from two normalized tests used in geriatric medicine to diagnose frailty and walking difficulties.

These two tests are the 4 Meters Walking Test\textsuperscript{19} (4MWT) and the Timed Get-up and Go Test\textsuperscript{20} (TGG).

The 4 Meters Walking Test measured the time for an elderly person to walk 4 meters, after 2 meters’ run up.

In our modified TGG, a chair is facing a wall (in our case 3m plus the length of the walker). The tester is first telling the volunteer he will have to stand, walk to the wall, turn back and go round the chair and seat down. We chose that version as we thought managing the walking aid around a fixed obstacle could bring extra information. TGG consists in a succession of basic mobility tasks: getting up from a chair, walking, turning round, walking back to the chair, going round the chair, sitting down.

**Description of the experiment**

Users volunteered after information by a geriatrician from the Toulouse Gérontopôle geriatric medicine department. We chose to propose participation to people, with motor (as assessed by 4M over 4sec and TGG over 13sec) and cognitive impairment (as assessed by MMSE below 26), and their main natural caregiver as healthy volunteer (for ethical reasons regarding consent of the cognitively impaired person). Participants should not have been using a walking frame prior to the tests. The recruiting was not random. Informed consent was obtained from both healthy and impaired volunteers. In the case of the cognitively impaired, the consent was also given by the main caregiver. No participant was under legal protection. All participants consented in being filmed and allowed films to be used for the purpose of the research.

The protocol would propose first the 4M, then the TGG. If the volunteer failed the 4M, the protocol would stop at that stage. Failed 4M was considered
as taking over ten times more time to complete the test with a device then walking the usual way of the volunteer (i.e.: with no aid or a different aid to a walker such as a cane). During each test, the volunteer was first trained to complete the test, then to complete it with first the regular walking frame then the robuWALKER (rW). Training lasted as long as the volunteer required to feel sufficiently confident. Each test was run right after training with a new device (usual way of walking then walking frame and rW).

Each training and test was filmed by a single camera, we had to choose the best point of view and this was left to the cameraperson. Total duration of step and double contact were assessed on a film section where the feet were visible, on a straight line with 3 steps or more at stable speed. This could be on 4M or a straight portion of TGG.

robuWALKER the smart-walker used
As to validate that protocol we used rW manufactured by Robosoft. rW is an indoor mobility platform designed for walking and sit-to-stand aid to elderly persons. Regarding mobility this technical aid is composed of 2 driving rear wheels and 2 caster wheels at the front. It has two motorized arms in order to help the elderly to stand from seated. Note that rW verifies the space standards for a wheelchair (Table 1).

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>L x 1 x h = 973 x 570 x 560 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground clearance</td>
<td>50 mm</td>
</tr>
<tr>
<td>Max speed</td>
<td>0.5 m/s</td>
</tr>
</tbody>
</table>

Table 1. robuWALKER technical characteristics

rW is allowing forward and backward motion, turn to the right and left and rising and lowering the handles. 2 buttons are offering the 3 functionalities (Fig.3). The button on the right handle allows: Walking forward (arrow at the front) or walking backward (arrow at the back),

Turning right (right arrow) or turning left (left arrow),

The button on the left handle allows rising the two handles at the same pace (up arrow) or lowering the two handles at the same pace (down arrow).

RESULTS
Population
Nine persons were included in the protocol: four healthy volunteers aged 71 to 86; five impaired volunteers aged 83 to 96. One healthy volunteer proved to have walking impairment (YCA) with 4M at 5.7sec and TGG at 19sec. As she had no cognitive impairment she had to be excluded from analysis. One impaired volunteer (MCO) had improved with MMSE = 26, 4M at 3.28 and TG at 12.24 and was thus requalified as healthy volunteer. Their characteristics are displayed in Table 2.

<table>
<thead>
<tr>
<th>User</th>
<th>Age</th>
<th>Gender</th>
<th>Size</th>
<th>Weight</th>
<th>With walking trouble</th>
<th>MMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAR</td>
<td>75</td>
<td>Female</td>
<td>1.72</td>
<td>49</td>
<td>no</td>
<td>irrelevant</td>
</tr>
<tr>
<td>HRU</td>
<td>71</td>
<td>Female</td>
<td>1.58</td>
<td>57</td>
<td>no</td>
<td>irrelevant</td>
</tr>
<tr>
<td>YCA</td>
<td>86</td>
<td>Female</td>
<td>1.63</td>
<td>62</td>
<td>no</td>
<td>irrelevant</td>
</tr>
<tr>
<td>YCO</td>
<td>77</td>
<td>Female</td>
<td>1.61</td>
<td>55.5</td>
<td>yes</td>
<td>irrelevant</td>
</tr>
<tr>
<td>MCO</td>
<td>80</td>
<td>Male</td>
<td>1.75</td>
<td>73</td>
<td>no</td>
<td>26</td>
</tr>
<tr>
<td>FSE</td>
<td>96</td>
<td>Male</td>
<td>1.70</td>
<td>75</td>
<td>yes</td>
<td>19</td>
</tr>
<tr>
<td>GCA</td>
<td>83</td>
<td>Male</td>
<td>1.72</td>
<td>80</td>
<td>yes</td>
<td>19</td>
</tr>
<tr>
<td>MGO</td>
<td>86</td>
<td>Female</td>
<td>1.48</td>
<td>55</td>
<td>yes</td>
<td>17</td>
</tr>
<tr>
<td>LSE</td>
<td>93</td>
<td>Female</td>
<td>1.56</td>
<td>55</td>
<td>yes</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2. The subjects

Time of completion
In table 3 we compare the time to complete each test for each of the eight volunteers. Six of them completed the two tests under the three different conditions.
One of them (LSE) could not succeed in the 4M test with rW and then was not proposed the TGG. One of them (MCO) could not succeed at TGG with rW.

<table>
<thead>
<tr>
<th>Users</th>
<th>4M usual</th>
<th>4M frame</th>
<th>4M rW</th>
<th>TGG usual</th>
<th>TGG frame</th>
<th>TGG W</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAR</td>
<td>2.92</td>
<td>2.70</td>
<td>17.19</td>
<td>11.74</td>
<td>23.98</td>
<td>90.76</td>
</tr>
<tr>
<td>HRU</td>
<td>2.65</td>
<td>2.52</td>
<td>15.12</td>
<td>9.90</td>
<td>13.68</td>
<td>58.59</td>
</tr>
<tr>
<td>YCA</td>
<td>5.7</td>
<td>5.4</td>
<td>15.12</td>
<td>19</td>
<td>30.7</td>
<td>58</td>
</tr>
<tr>
<td>MCO</td>
<td>3.28</td>
<td>2.56</td>
<td>26.64</td>
<td>12.24</td>
<td>21.91</td>
<td>112.48</td>
</tr>
<tr>
<td>FSE</td>
<td>5.31</td>
<td>6.70</td>
<td>14.85</td>
<td>27.99</td>
<td>31.68</td>
<td>82.57</td>
</tr>
<tr>
<td>GCA</td>
<td>8.68</td>
<td>8.77</td>
<td>10.66</td>
<td>34.24</td>
<td>32.69</td>
<td>99.54</td>
</tr>
<tr>
<td>MGO</td>
<td>4.59</td>
<td>3.87</td>
<td>8.73</td>
<td>24.03</td>
<td>30.15</td>
<td>54.09</td>
</tr>
<tr>
<td>LSE</td>
<td>8.86</td>
<td>12.73</td>
<td>119.65</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 3. Time in seconds to perform tasks

Analysis of videos
It was possible for each user to assess the expected values. Tables 4 shows the durations of steps with the regular walking frame (D) and rW, the ration between those, the ratio of one double contact to the total duration of step with D and rW, then the difference of those ratios. In elderly healthy users, the duration of step with rW increases 1.8 to 3.4 times, double contact 4 to 9 times, the median increase of double contact ratio is .15. In impaired users there is a lesser or no increase in step 1 to 1.5, a lesser increase in double contact 1.3 to 2, the double contact ratio just increasing .05.
Table 4. Characteristics of steps with either aids

<table>
<thead>
<tr>
<th>Users</th>
<th>step duration D</th>
<th>step duration Rw</th>
<th>ratio</th>
<th>double contact D</th>
<th>double contact Rw</th>
<th>ratio difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAR</td>
<td>1.04</td>
<td>3.52</td>
<td>3.38</td>
<td>0.11</td>
<td>0.96</td>
<td>0.17</td>
</tr>
<tr>
<td>HRU</td>
<td>0.96</td>
<td>1.84</td>
<td>1.92</td>
<td>0.08</td>
<td>0.40</td>
<td>0.13</td>
</tr>
<tr>
<td>YCO</td>
<td>1.28</td>
<td>2.60</td>
<td>2.03</td>
<td>0.16</td>
<td>0.40</td>
<td>0.03</td>
</tr>
<tr>
<td>MCO</td>
<td>1.04</td>
<td>1.92</td>
<td>1.85</td>
<td>0.16</td>
<td>0.64</td>
<td>0.16</td>
</tr>
<tr>
<td>FSE</td>
<td>1.52</td>
<td>2.24</td>
<td>1.47</td>
<td>0.24</td>
<td>0.48</td>
<td>0.06</td>
</tr>
<tr>
<td>GCA</td>
<td>1.60</td>
<td>2.09</td>
<td>1.31</td>
<td>0.32</td>
<td>0.48</td>
<td>0.03</td>
</tr>
<tr>
<td>LES</td>
<td>1.52</td>
<td>1.52</td>
<td>1.00</td>
<td>0.24</td>
<td>0.40</td>
<td>0.11</td>
</tr>
<tr>
<td>MGO</td>
<td>1.20</td>
<td>1.36</td>
<td>1.13</td>
<td>0.24</td>
<td>0.32</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Discussion

Due to the small amount of time of availability of the nW we chose to select people with no previous experience of walkers to avoid a training bias against the tested device. Completion times are showing that the tested walker is less efficient than a regular walking frame, but the smaller effect on the profile of steps as compared to that on healthy users could be a clue of a better adaptation to those in need. Healthy users could be pushing the nW due to it’s nominal speed being to slow for them. Two patients failed in using the device, this might be due, if we consider that speed and ergonomics are fitting (from the effect on step parameters) to a human robot interaction (HRI) problem; we could see that from the clinical analysis of posture and use on the videos. Quantified data could not asses getting up. In further tests we will increase the number of cameras to have different points of view to avoid dead angles and allow for posture analysis (tilt, distance of body to handles, special issue of getting up) and have a special focus on HRI (that would not be allowed by optokinetics).

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The mechatronic shoe: A new rehabilitation tool for improving mobility

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Purpose Our aim is to apply a rehabilitation device in household. The development of a rehabilitation device is based on the principle of the exoskeleton. Method We describe the mechatronic shoe developed as result of research in 7FP-project SMILING with application in geriatric rehabilitation medicine. The overall objective is to develop and construct an advanced prototype of a wearable non-invasive computerized miniature rehabilitation device for mechanical chaotic perturbations of gait pattern in order to counteract and prevent tendencies to fall. The main tasks were to develop perturbation algorithms fitted to suit individual user’s specific needs and to implement a training system to be used in rehabilitation, health care, and fitness centers for a reorganization of the rehabilitation process in ageing. The SMILING shoe is a complex mechatronical system that requires interaction of various sensors data, mechanical components, and human activity. Two different designs were developed: STRATH and TUKE. Both left and right shoes are equipped with 4 mechanical units driven by DC-motors. Two are in the front and two are in the back side. In generally, mechanisms change the height after each or several steps, and in such way they change inclinations of the shoes sole in two planes – frontal and sagittal. The SMILING shoe is worn on a standard shoe used by user. The user has to react to changes of the shoe inclinations to stay balanced when walking while completing specific tasks. Beside the SMILING shoe, we are working on the development of a rehabilitation robot for upper limbs using pneumatic air muscles. The robot is designed on the principle of exoskeleton and is intended for the rehabilitation of the shoulder and elbow; the device has 4 degrees of freedom and uses an antagonistic pneumatic air muscles arrangement. Results & Discussion In the testing phase, 4 pairs of the SMILING shoes produced by the University of Strathclyde were tested in clinical trials with senior users. The objective of the trials was to determine whether a training program with SMILING shoes enhances gait performance. Seniors from Israel, Italy, Slovakia, and Switzerland participated in this cross-over randomized-controlled trial. In Slovakia we cooperated with the Highly Specialized Geriatric Institute of St. Lukas Košice.

Keywords: rehabilitation shoe, mechatronic, automatization, robot

INTRODUCTION
The ageing of population, numerous but also relative incensement of higher age groups of population is primarily result of progress in economic, social and medical field and it presents global problem of society with extensive impact on economic growth of the country. The EU countries within the context of ageing population over 65 (according to the EU countries the number of elderly will grow in 2025 to 21.7%1) are struggling with decrease rhythm of economics, which impact the use of public finances, funding of the healthcare mostly. The changes connected to the natural ageing impact basic movement structure of human, i.e. walk and other motoric tasks, which are part of the everyday tasks. One of the critical situations in the life of elderly is fall. The main cause of falls in old age is reduced ability of quick postural adaptation to the changing and hindered conditions2. Every year 1/3 of seniors suffers of fall and almost 2/3 of these people suffer of fall frequently. Falls can bring light injuries without the need of long-term hospitalization (25%), but in most cases the serious injuries are ensued, such as fracture of femur cervix (90% of these fractures are caused by fall among over 65), traumatic head injuries which can lead to the increase of the early death or permanent disability (10-15%)3. The risk of death caused due to the health complications by fall is increasing pro rate with age and the number of 16.4% in Europe is very high3. European commission have coordinated the research in connection with the ageing of population within the project „More Years, Better Lives - The Potential and Challenges of Demographic Change“ on several summits. The main idea of the project is that the member states participate to the initiative of the programming of the research in the areas such as research of the possibilities of helping the elderly to stay active as long as possible, in good health with better life quality and also to ensure to keep the healthcare systems in the future4. One option how to provide the better quality of life of elderly is creating of conditions and resources for prevention and social inclusion. Today’s direction of the fulfilling the aims of the programmes in member states are highly influenced by the technical progress and development of the tech-
Technologies. Several European researches are oriented to this area of development of ICTs in connection with providing of the social care. At our department, we deal with development of the new complex diagnostic and rehabilitation system focusing on the people with risk of fall, with the possibility of rehabilitation in household.

Programmes Oriented to the Development of ICT for People with Risk of Fall

Technological innovation, omnipresent in the field of computer techniques, sensor networks, mobile devices, contribute to the incensement of independence, safety, in home environment in several daily activities though increasing the presumption of maintaining the social contact with psychical support and physical stimulation. European research in the field of ICTs deals with the projects oriented to the technologies creating intelligent environment and embedded systems using wire and wireless networks, different sensors of environment parameters or user status in terms of health but also identification of non-standard situations in daily activities its aim to increase the quality of life and social inclusion of elderly as well as people with disabilities.

Project Domeo

The focus of the project communication with healthcare centre through the digital network is support and development of assistive robotic systems, which enable learning by physical simulation to users. The support is directed to two platforms:

1. RubuMate – for verbal and nonverbal interaction with user (Fig. 1 top)
2. RubuWalker – oriented more on the physical side of the help for help with walk, sitting and rising, monitoring vital functions and data processing (Fig. 1 bottom)12.

Project VitaliSHOE

Project VitaliSHOE (shoe with embedded sensors) (Fig. 2) is developed to monitor movement during the walk with focus on the prevention for falls and injuries. Several types of sensors are installed in the sole of the shoe to detect the obstacles and prevent the fall among elderly13.

Project BioSensing

A sensor system was developed that quantifies simultaneously body acceleration, knee angle (Fig. 3), foot pressure (Fig. 4) and repetitive loading patterns of the knee joint during activities of daily living. Patients get feedback if they move too much, too little, or move in the wrong way. The sensor system consists of a smart knee brace that measures the knee angle (developed by TNO), a combined angular velocity and acceleration sensor (McRoberts), a foot sensor (Zephyr/TNO), a data acquisition system (IDEE), and a wireless communication system (IDEE/Neways). Data is uploaded to a webserver and presented via a web application. Demonstrators were created for the medical specialist (diagnostics), for the physiotherapist (training), and patients at home (training, monitoring)14.

Fig. 1. Robotic assistance systems based on platforms and RubuMate and RubuWalker12

Fig. 2. VitaliSHOE – location of sensors in shoe soles13

Fig. 3. Knee brace (left), Demonstration of the hybrid sensor: measuring knee loads (right) – BioSensing14
MATERIALS AND METHODS IN THE SMILING PROJECT

We describe the mechatronic shoe developed as result of research in 7FP-project SMILING with application in geriatric rehabilitation medicine [1-6]. The overall objective is to develop and construct an advanced prototype of a wearable non-invasive computerized miniature rehabilitation device for mechanical chaotic perturbations of gait pattern in order to counteract and prevent tendencies to fall.

The main tasks were to develop perturbation algorithms fitted to suit individual user’s specific needs and to implement a training system to be used in rehabilitation, health care, and fitness centers for a reorganization of the rehabilitation process in ageing.

The SMILING shoe is a complex mechatronical system that requires interaction of various sensors data, mechanical components, and human activity. The SMILING shoe is worn on a standard shoe used by user. The user has to react to changes of the shoe inclinations to keep balance when walking while completing specific tasks. Both left and right shoes are equipped with 4 mechanical units driven by DC-motors. Two are in the front and two are in the back side. In generally, mechanisms change the height after each or several steps, and in such way they change inclinations of the shoes sole in two planes – frontal and sagital.

Two different mechanical designs of SMILING shoes were developed: STRATH (Fig. 5) and TUKE (Fig. 6).

DIAGNOSTICS AND REHABILITATION SYSTEM

Development of complex system for diagnostics and rehabilitation is divided into two functional modules. Development of the diagnostic part lies in the design, testing and verification of objective qualitative and quantitative methods and means for detecting abnormalities in human walking stereotype that predicted the risk of falls. Qualitative evaluation includes clinical testing of mental and physical condition of the patient, through clinical standard - physical and cognitive functions tests. Walking stereotype was evaluated by qualitative methods. The experimental part of gait analysis was conducted at our Laboratory of Movement Analysis, which is equipped with systems allowing linear (via opto-SMART-kinematic analysis, two piezoelectric force plates Kistler - kinetic analysis) as well as nonlinear (via Gyro) analysis of the motion activities.

The rehabilitation part of our system is using motorized rehabilitation shoes developed in the SMILING project - Self Mobility Improvement in the elderly by counteracting falls Nb.215493 (2008-2010)5,9,10,11. However, our current approach to rehabilitation training is modified. The essence of the training program is not focused on a series of exercises to increase muscle strength and nature of joint mobility, as most of the traditional rehabilitation programs, but the dynamic behavior of the human motor system during walking while providing regular daily life physical activities (carrying out normal activities at home).

SMILING shoe architecture

In our current experiments we use TUKE version of rehabilitation shoes. As we said shoes are a complex mechatronical system that requires interaction of sensors, data, mechanical parts and human activity. Mechatronical concept of the rehabilitation shoe is on (Fig. 9). The main components of mechatronical concept consist of mechanical unit, motor control unit MCU (Fig. 7), Swing detector with wireless communication unit named S-modules based on gyro and accelerometer (Fig. 7) and user control unit UCU (Fig. 8)5.
The MCU must store suitable set of perturbation patterns and drive motors according these perturbations. Driving of motors by MCU must be synchronized with a human walking activity that is detected by an external accelerometer and gyroscope processing (S-Sense) unit. The architecture of MCU is optimized for acquisition and fast processing of relevant sensors data and control of mechanical actuators used in the SMILING shoe. Control algorithms embedded in the MCU firmware were tailored to the parameters and limitations of mechanical actuators used in the SMILING shoe. Optimization of MCU firmware for tuning of mechanical parts after assembling and durability testing of complete SMILING shoe was also done in order to support MCU by delivering signals for perturbations to shoes which are induced by motors.

Each shoe is equipped with four independent mechanical actuators powered by DC motors, two in front and two in the rear (Fig. 10).

The motors are in motion only during the swing phase of gait cycle. Swing phase detection is performed in real-time algorithm running in electronics of the shoes, which processes signals from internal sensors. These sensors, electronics and wireless modules are embedded in IMEC modules for wireless data transmission and S-module to record 6-D gait parameters using gyroscopes and accelerometers. The vertical distances of perturbations are changing by motors, to eject shoes that limb swing phase just completed and smoothly passed to a support phase. It also changes the slope of the base shoe, which is the backbone limb exposed to unpredictable environmental change. Predictions of changes of perturbations are based on a previous character of actions. Perturbations are induced by the chaotic signal generating algorithms and theory of dynamical systems. Perturbations tend to vary independently of the base shoe to ± 10° in the sagital and frontal plane and the change in height of up to 15 mm.

**Training program**

Training program with motorized mechatronical shoes (Fig. 11) aims to improve the function of stability while walking. Change the height and tilt base shoe simulates changes in the external environment in which a person is forced to balance the body’s centre of gravity to maintain stability and to involve the sensory, effectors, and the neural system. Constant stimulation of the neural system shall disturb incorrect habits and improve elasticity and nerve responsiveness.

It was expected that user will learn a new stereotype walk in carrying out rehabilitation activities dealing with unexpected stimulus from the external environment and to overcome the uncertainty and fear when walking.

An important task of the research was to manage control of mechatronical components of TUKE shoes.
Clinical validation procedure

Four pairs of SMILING shoes were built, to be used for the trials. Each system was fully checked and tested before the release to the clinical centres, to avoid as much as possible technical problem during the trials. The validation and tuning plan completed the research activities of the project. The system was used by about 100 elderly persons in Israel, Italy, Slovakia and Switzerland, to evaluate its efficacy and to define the best training programs to improve mobility and walking. A randomised controlled cross-over study was performed, including 4 weeks of training using the SMILING shoes including perturbation and 4 weeks of training with placebo dummy shoes that does not include perturbations during walking.

The task for SMILING project validation was:
- Validate the effect of training with chaotic perturbation on linear and non-linear gait parameters and on functional tests relating to walking and balance.
- Validate the safety and acceptance of the SMILING system by the target population defined with the main limitations, age ≥ 65 years, able to walk at least 20 meters independently, i.e. without personal assistance and without an assistive device, except for a single point cane, one or more falls in the previous year (falls during sport activities excluded).
- Standardized physical and cognitive functional tests Tinetti's POMA score between 22-26.

Preliminary results showed some improvement in gait performance with the SMILING training. For instance, gait speed and stride length increased, and double support tended to decrease during SMILING training. To approve statistically the efficacy of SMILING training, we need to provide more clinical tests and do cross-over analysis in the entire recruited samples.

CONCLUSION

SMILING rehabilitation shoe and program was designed in frame of the international project SMILING with cooperation of clinical departments. The verification of SMILING rehabilitation training influence on senior's stability during walking were published in several pilot studies in terms of kinetic gait analysis, which confirmed the positive impact of rehabilitation on the system stability and dynamics of walking.

ACKNOWLEDGEMENT

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References

Flowing matter: Robotic fabrication of complex ceramic systems

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Purpose This research investigates the possibility of adapting industrial fabrication methods to produce mass customized ceramic components for complex tectonic systems. The aim is to bring the practice of building ceramic structures close to the contemporary production context by proposing a revision of a well-established production method – clay extrusion – and informing it with deep computational design and robotic fabrication techniques. Method The envisioned industrial scenario is emulated by fabricating a series of ceramic prototypes through the use of a 6-axis robotic arm equipped with a wire-cutting tool, developing ruled-shaped interlocking clay units for the creation of innovative load-bearing walls. A systematic workflow allows for the direct stream of information from a parametrically-discretized input surface to the generation of cutting paths for shaping clay bodies through the robot. Results & Discussion The combination of high-tech computational design and robotic fabrication processes with low-tech onsite assembly allows for the generation of serialized mass-customized ruled-geometry ceramic units for hybrid structures, such as doubly-curved load-bearing walls with enhanced structural performances. The result is a fast, economic, and efficient way to fabricate highly differentiated ceramic components with the use of robotic technologies.

Keywords: robotics, industrial automation, ceramic structures, computational design

INTRODUCTION

Ceramic materials have a long history as a building material in architecture, and are used in structural, cladding, and decorative applications. Today’s dominance of flat rectangular tiles – a ubiquitous ceramic building component – is now challenged by newly emerging numerically controlled methods of ceramic production and assembly. Both craft-based tile manufacturing and high-volume industrial production of clay-based ceramics are affected by digital and robotic fabrication techniques but the potential for these new tools to enable new ceramic products remains in their infancy. Of particular interest for architects is the plasticity of clay based ceramics prior to the kiln firing – a property that potentially allows for the realization of novel complex forms. Rather than merely designing a novel ceramic part, this paper presents an approach that addresses the material and its associated processes as an integral and inseparable unit. Only the synergetic consideration of both – paired with novel prototyping approaches using an industrial robot – leads to the proposal of an innovative building component that can be feasibly produced in the context of the contemporary production of architectural ceramic. This approach was the subject of the course “Material Processes and Systems: CeramicLab” taught by Prof. M. Bechthold and Nathan King in the fall of 2011 at the Graduate School of Design at Harvard University. The project presented here takes a particular interest in the design and construction of complex tectonic shapes. The resulting forms combine traditional as well as new methods of surface discretization. The basic building component is a newly designed interlocking block which has been conceived of as a mass-customized element. Following an analysis of typical industrial production processes for ceramic architectural elements, the team decided to develop a new variable structural ceramic block based on a novel variation of the widely used extrusion process.

The project addresses the long-standing problems inherent in the construction of complex form using traditional brick-laying techniques and standard bricks. In order to create non-orthogonal, complex overall forms mortar joints that are normally approximately 1 cm in thickness have to vary in size, resulting in highly differentiated mortar patterns on the finished surface. Complicated and expensive scaffolding systems for both guiding and supporting the ceramic units are normally required during the construction of such complexly shaped structures. As skilled craftspeople are no longer widely available, and considering high labor costs in the construction industries of industrial economies the realization of complexly shaped ceramic surface forms has become highly problematic.

Addressing these problems, the research explores the opportunities specifically associated with the merger of high-tech industrial production processes
of customized components with low-tech on-site assembly. A novel variable extrusion process was developed and prototyped using a robotic work cell. The resulting twisted and curved block elements are evaluated in the context of several design prototypes that derive novel design expressions through the availability of mass customized ceramic components.

The research proposes to enhance standard industrial extrusion processes with a variable wire cutting module that allows the production of components with a wide variety of curved but ruled surface geometry. The industrial production context was emulated through the deployment of a prototypical robotic wire cutting process driven by an integrated digital workflow. Precisely interlocking units were designed and produced using the system. In the construction context these newly shaped ceramic blocks might eventually reduce or even eliminate the need for temporary guiding systems and reduce the use of temporary supporting structures. In addition, a ruled discretization method would allow for a smoother definition of complex spatial surfaces. Finally, the resulting geometry of the overall interlocking system may introduce enhanced structural stability especially when combined with post-tensioning methods.

This paper first reviews construction precedents – both and historical and contemporary – of complexly shaped tectonic ceramic forms. It then describes the established industrial production of ceramic components with a focus on identifying opportunities for implementing robotic technologies for producing computationally designed ceramic units. The envisioned industrial environment is finally simulated through the use of robotic wire-cutting techniques for the fabrication of a series of prototypes that serve as a proof of concept.

BACKGROUND AND PRECEDENTS
The traditional stone construction techniques of pre-medieval periods are among the first precedents of complex block surfaces. Stone elements were often customized according to their location or structural role, but preference given to the use of similarly shaped elements that culminated in the central keystone. This logic has continued in the construction of later vaults and domes, generating more spatially complex masonry structural systems. Gothic architecture employed more advanced versions of earlier stone and brick vaulting techniques in the pursuit of seemingly lighter, intricate structural patterns. Of particular significance in more recent periods are the works of Eladio Dieste and Rafael Guastavino. Both devised novel construction systems of structural ceramic surfaces using standard format tiles. Dieste’s structures require an extensive scaffolding system – but he was able to achieve relatively complex forms. Guastavino, on the other hand, remained largely constrained to relatively simple dome and vault shapes – his innovation was focused on the much reduced need for temporary scaffolding systems and improved fire resistance of horizontal spanning systems.

Another relevant historical precedent is Antonio Gaudi’s Sagrada Familia, whose ruled-geometry building components required the expertise of highly skilled craftsmanship.

In traditional dome construction, brick and stone layers are horizontal rings. Typical Arctic Igloo construction employs ice blocks manually shaped on site, and assembled following a spiral pattern such that the blocks form an interlocking structure. A more recent example of curved brick surfaces is David Wendland’s Experimental Construction – a research project culminating in the erection of a free-form shell masonry structure that required the employment of an intricate doubly-curved scaffolding system for holding and guiding the assembly. The free-form Catalan thin vault by Philip Block’s BLOCK research group also served as an important precedent, particularly for its non-standard discretization of masonry structures. Relevant to the research is also the work of Martin Speth, who has developed doubly-curved masonry vaults made of prefabricated components. These examples all deal with complex shape, rely on an external means of prescribing overall geometry on site, and accommodate surface curvature through variation in the thickness of mortar joints - none deploy a custom shaped block element.

Several emerging technologies are available to assist with the assembly of complex structures on site. GPS-assisted construction approaches are being actively developed, and barcode systems are used to manage large sets of individualized components on contemporary construction sites. Both technologies are potentially relevant within the context of the
research presented as they can guide the assembly of numerous highly differentiated building components. One of the few broadly implemented mass-customization systems in brick and block construction is the German Xella system by Xella Kalksandstein GmbH’s production logic. Here, sets of blocks that combine custom and standard formats are configured and delivered on site using just in time strategies thus eliminating the time-consuming and wasteful cutting of blocks on site, and facilitating the decrease in construction time through the deployment of small cranes operated remotely by masons. While this system does employ custom pre-cut units it is currently only used in the construction of flat walls.

**PRINCIPLES, PROCESSES, AND OUTCOMES**

This design proposal is conceived as a design research investigation whose objective is to develop a prototypical manufacturing scenario that can be used to evaluate design assumptions, material properties, fabrication constraints, and assembly logics of the proposed process intervention. The research is carried out under the hypothesis that the use of custom shaped ceramic components incorporating off-site robotic wire-cut ruled geometry embeds global geometric intelligence and allows for low-tech on-site assembly while achieving complex doubly-curved continuous-surface ceramic structures with interlocking components. This research project links the established industrial production of ceramics with the intelligence of computational design and digital fabrication by intervening in a standardized production process—extrusion—through a novel use of robotic technologies.

**INDUSTRIAL CLAY EXTRUSION**

Industrial clay extrusion is a process in which ceramic components are produced in a serialized and continuous linear manner. During the process a helical extrusion mechanism forces clay through a die that imposes a continuous shape on the material. The extrusion die represents one of the only integrated mechanisms for custom shaping in industrial ceramic production. Custom extruded sections come a cost premium associated with die development that must be justified by a significant production quantity allowing for the production of many of the same custom components rather than individually differentiated parts. During extrusion, components are supported by a conveyor or roller system that carries the extruded elements through several automated production cells that dimension, fire, finish, and package the ceramic parts.

Fig.2. Examples of potential complex tectonic systems

Fig.3. Industrial processes of clay extrusion (Image courtesy of the Design Robotics Group, Harvard GSD)

Dimensioning of individual linear elements is often accomplished by automated and exactly coordinated wires or blades that make cuts perpendicular to the extrusion direction. The proposed process intervention adapts the integrated dimensioning cell to incor-
porate a numerically-controlled wire-cutting tool designed to enable shape customization of single elements during linear processing. In this scenario robotically-guided wires are programmed to cut each component along ruled surfaces. Part dimensioning during industrial extrusion is characterized by wire-cutting that, when numerically controlled, could achieve complex ruled surfaces on all non-supporting block faces. By addressing customization through the intervention in a single production cell within the larger extrusion system the proposed process would enable the manufacturing of mass-customized ceramic elements defined by ruled geometries.

**Fig. 5. Envisioned industrial custom-shape cutting**

**RULES SHAPED CUSTOM COMPONENTS FOR COMPLEX TECTONIC SYSTEMS**

The proposed combines the CNC wire-cutting of ruled-geometry with and intelligent computational design approach for use in the design and construction of complex ceramic structures. A rigorous computational method was developed to optimize a surface discretization with customized units that embed the following characteristics:

- The traditional masonry logic including an arrangement of staggered components for optimal structural performances.
- A precise interlocking system, in which each component aligns with the ones around it.
- A smooth subdivision of the surface, with linear-seams representing edge lines of singular ruled surfaces.
- A potentially enhanced static behavior, with an increased shear resistance of the overall structure over traditional brick walls.

**Fig. 6. Interlocking logic embedding geometric assembly intelligence**

The developed algorithm, implemented in a C# component for Grasshopper™, the graphical algorithm editor for the design software Rhinoceros™, allows for a straightforward discretization of input surfaces with a series of parameters that allow a flexible customization of the system's geometric properties. The algorithm constitutes the first step in a linear workflow from the digital conception of the tectonic system to its components' fabrication and the final structure's assembly. Following this logic, the developed computational method allows the extrapolation of geometric information needed for an automated fabrication process. For each ceramic component the algorithm outputs wireframe data that serves as guiding lines for the ruled-geometry wire-cutting method.

**Fig. 7. Enhanced shear resistance through volumetric seams**

**PROTOTYPICAL OFF-SITE ROBOTIC FABRICATION**

Consistent with most commercial masonry construction systems the proposed system utilizes off-site production of individual units. To facilitate the exploration of of-site mass customization established by the proposed production system an automated robotic programming workflow was used to derive machine code from the previously described digital geometry within the same Rhinoceros™-based digital design platform.
Industrial numerically controlled wire-cutting was simulated during prototyping by a 6-axis industrial robotic manipulator that was used to guide a custom end effector that employed a steel cutting wire. For each individual component the workflow began by processing the input data derived from the digital model. First, the wireframe geometries describing the unit’s edges are used to define ruling lines and generate the wire-cutting information for the robot. Once positioned relative to the robotic work cell these lines served in the generation of cutting paths along five sides of each element.

In contrast to previously published work\(^1\), automation of robotic programming was facilitated by the Hal\(^{TM}\) plugin for Grasshopper\(^{TM}\) which was used to generate, simulate, and optimize each of the paths. To further verify the cutting path, each robotic movement was simulated in proprietary ABB simulation environment RobotStudio\(^{TM}\).

A custom fixture was created to support the wet clay block during cutting. To facilitate maximum robotic freedom the fixture supported the clay well above the work surface using a stanchion that engaged the material platform inboard of the stock perimeter allowing the tool to realize the undercut geometry needed for the interlocking units. Finally, a numeric labeling was used to identify each unit during assembly.

Multiple prototypes were created to better understand the application of different ceramic compositions (terracotta, porcelain, T1, and brown stoneware). An analysis of the prototypes revealed that the accuracy of the cutting process is the result of the combination of several aspects: moisture and grog content within the clay, adhesion level (meaning how difficult the cut part is to remove from the stock), wire tension and cutting speed. Further testing revealed that a clay of relatively high grog content, with high green strength, that is designed for low shrinkage gave the best finished results of all tested bodies. Additionally, if the drying and kiln schedule is regulated, shrinkage can be predicted within acceptable tolerances in the geometries tested (Figure 10). Further investigation is required to determine the full impact of material shrinkage which, as seen in figure 13, can have an aggregate impact on the overall surface geometry.

**Prototypical on-site assembly**

The described ceramic components are characterized by an inherent geometric logic that can be used to indicate assembly sequence. This logic, when combined with an assembly drawing and factory applied numeric coding system, allows for intuitive onsite assembly, a limitation of many mass-customization proposals.
Two full-scale sectional prototypes were developed to test the potential of structural assemblies. The first structure (Prototype A) is an experimental application of the overall process of interlocking discretization of a complex surface. The second (Prototype B) investigates a more speculative use of the ruled-geometry logic for design compositions.

Prototype A is formed by interlocking custom components made out of a T1 stoneware with a fine grog content. This prototype tests the ability of the system to create doubly curved surfaces and the on-site assembly logic. While the assembly sequence was consistent with expectations the aggregate shrinkage impacted the ability of the structure to self-support during assembly. Additional testing is in progress to resolve these tolerance issues through manipulation of the computational geometry, controlled drying and firing, and clay body specifications.

CONCLUSION AND OUTLOOK

The presented research proposed an industrially integrated process allowing for the manufacture of mass-customized structural ceramic elements through the introduction numerically controlled cutting to the clay extrusion process. The combination of high-tech computational design and robotic fabrication processes with low-tech on-site assembly resulted in the generation of highly differentiated ruled-geometry ceramic units for complex tectonic assemblies.
ACKNOWLEDGMENTS

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8. Ibid.
Robotic Tile Placement: Tools, Techniques and Feasibility

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Purpose The project develops an integrated digital workflow for robotic tile placement, a novel construction method that allows for off-site use of industrial robotics for on-site tile surfaces, and a feasibility study for implementing the approach in the context of the tile industry. The proposed approach overcomes limitations of existing methods that focus merely on efficiency. Instead, the proposition of the research is to enable the installation of unique, one-off, and highly complex tile patterns impossible to install economically by hand. Method The research uses a design experiment to develop computational and robotic technologies. Several design studies were prototyped as a proof of concept. Issues of construction integration and industry implementation were researched and advanced through interviews with experts in the field, field studies, and an extensive literature research that includes a review of U.S. tile installation standards. Results & Discussion The novel workflow includes several computational approaches to generate tile patterns too complex to install economically by hand. Weighted randomness or patterns processed based on the analysis of bitmap images produce tile patterns within the cost-effective Rhinoceros platform. Robotic code for the running of a robotic work cell is created automatically by the integrated code generator. The code can be simulated through a newly integrated tool that permits tool path visualization as well as cost and time estimates. Regarding construction integration the research largely replaces manual tile installation to a high degree. The paper describes logistics and installation strategies for pre-tiled panels along with recommending specific material combinations. An initial feasibility study identifies fundamental parameters such as set up and placement times, adhesive application, and many more. The study allows an estimation of basic cost parameters in the context of specific construction markets, based on an assumed value of a niche tile product that employs highly complex patterns. Robotic tile placement ultimately adds value for tile producers by moving installation of specialty tile patterns to the place of tile production.

Keywords: robotics, ceramic tile, computation,

INTRODUCTION
The steady increase in the price to productivity ratio of industrial robots over the past decades is opening up new application areas that include the production of architectural ceramics. Research at Harvard University’s Design Robotics Group (DRG) has been studying specific opportunities for integrating robotic technology with an initial focus on product customization and related workflow. 1 The research presented in this paper summarizes a feasibility study of robotic tile placement, an area that has received little attention in recent years. The research developed a computational environment that facilitates the generation of image or pattern-based tile designs and an integrated design-to-robotic-fabrication tile placement workflow. Both are based on the low-cost and widely available digital design software platform Rhinoceros™ (Rhino).

The integration of robotic tile placement into the construction industry requires a re-design of current placement strategies. The envisioned system can be considered a true mass-customization approach whereby the cost of the customized product is similar to that of the standard product. The added value of complex tile pattern designs does not come at a cost premium.

Once tiles have arrived at the point of installation, the state-of-the-art, computer-controlled, high-volume tile production-to-distribution process rapidly downgrades into a purely analog handling of the material. Tile installation remains a manual process, supported by simple tools that have remained unchanged for decades. Tile installers and tile producers have few common points of contact and take little mutual interest in their related, yet sharply separate, domains. Innovation in production has not transferred to installation with its many small geographically and economically fragmented participants. Issues of tile installation warrant a new study in the context of advances in robotic technology.

In developed economies with high labor rates tile installation costs remain a major factor in the overall cost of tiled surfaces. For example, in Boston, MA, unionized tile installer labor costs for laying mosaic tile on 1 ft² netting is 30-35 $/ft² and non-union labor is 15-20 $/ft². An increasingly felt shortage of qualified construction workers especially in the United States and elsewhere has aggravated already exist-
ing issues of installation quality. The range of feasible tile patterns is extremely limited and highly repetitive, poorly reflecting the sophisticated production technology underlying contemporary tile production.

To address these current problems of tile installation, and in an attempt to bridge the gap between producers and installers, the research investigates the use of robotic technology for tile installation as a way to address cost, time, and quality, both in terms of accuracy and design.

Existing approaches to robotic tile placement are reviewed first, followed by a report of the research conducted by Harvard’s DRG. The study concludes with a discussion of issues regarding implementation and construction integration, as well as an overview of next steps needed for industry integration.

**TILE INSTALLATION: STATE OF THE ART**

Currently the production of complex tile patterns exists in the form of pre-assembled mosaic tile sheets, a largely automated process. While individual sheets contain complex arrangements they are used in aggregate to form repetitive patterns without the possibility of customization. The majority of custom ceramic tile mosaics are assembled by hand but several precedents do exist for the robotic placement of custom tiled mosaics. Artaic, for example, a small Boston based commercial producer of custom mosaics, uses a single robotic work-cell to fabricate custom mosaics. During the Artaic process a digital image is discretized into tile pixels using proprietary color matching software and then divided into standardized 1ft² sheets. Each tile pixel is robotically placed into a registration grid and an adhesive sheet is applied to support the pre-assembled mosaics during shipping and installation where they are installed and grouted by hand.

A similar, yet fundamentally different, variation is used by Top Hat Tile, which achieves image-based customization of tile mosaics through individually glazed tile pixels. In this example a 1 ft² assembly of small, unglazed tiles is loaded into a custom robotic work cell that applies or prints a custom solid colored glaze on each individual tile. Again, the robotically assembled mosaics are installed in 1 ft² sheets by hand.

It should be mentioned that while the implementation of direct inkjet printing to create surface patterns and images, often on larger tiles, is seen in the tile industry, it is outside of the scope of this study.

**CONCEPT AND WORKFLOW DEVELOPMENT**

Today tile installation is done almost exclusively by hand. During this study opportunities for robotic installation were explored through two prototypical scenarios that addressed the process from computational design to physical implementation. Using integrated computational design, two modular workflows were used to generate the arrangement of tiles, as well as the machine code used to drive the robotic placement. The first workflow uses a randomized pattern of standard tiles with varied dimensional format. The second uses dimensionally modular tiles to recreate a digital image within the contrasting grout lines.

**Computational Tile Patterning**

The digital workflow for creating robotically placed ceramic tile panels consists of four components. Two are used to generate parametric tile arrangements, and two are used in the robot code generation, simulation and validation. For this research all of the modules were in the form of custom components written in C# for Grashopper™, the visual programming interface for Rhinoceros.

![Fig 1. Generated pattern using weighted randomness.](image)

**Pattern Based Digital Workflow**

A series of algorithms were developed to enable packing tiles of various formats into orthogonal patterns characterized by various degrees of regularity and randomness. Packing areas, defined by curves, and the resolution of the grid on which the pattern is based are the primary parameters of the system. Variables control the degree of randomness in the pattern and the number of tiles of each format. The pattern can accommodate any tile size, however, when using standard tile formats whose dimensions are not necessarily perfect multiples of each other, the script allows for irregular tile spacing in order to accommodate the discrepancies. Possible applications of this system include situations where there is a desire to create patterns possessing a degree of irregularity while using standard format tiles.
Fig 2. Image-based process converts a grayscale image into a tile pattern. The image is recreated through the density of grout lines.7

Image Based Digital Workflow
The image-based strategy uses the density of the grout lines in order to express the tone variations of the input image. As a proof of concept an iconic portrait of Marilyn Monroe was chosen to demonstrate the ability of the script to recreate something as complex, and uniquely identifiable, as the human face.

Expanding upon the pattern-based system the image-based workflow focused on maintaining equal spacing between tiles thus requiring the use of a modular tile system dimensioned on a grid. A grayscale image is used in order to drive an adaptive subdivision scheme which results in smaller tiles clustered near either darker areas or sharper edges. A grayscale translation (Fig 2) creates the most photorealistic result by converting lighter areas to larger tiles with fewer grout lines. In addition, it is possible to give the impression that tiles are following the contours in the image by increasing the grout areas and rotating the tiles so that they align with the image gradient.

Integrated Programming of Robotic Placement
The third module in the workflow converts any set of Rhino surfaces, representing tiles, into a series of movement commands for the ABB robotic arm. In Fig. 3 the lines indicate this robotic movement sequence, from a source point, to an intermediary point above the source, across the table to an intermediary point above the destination, and finally directly down into the destination. Intermediary points are necessary in the movement to avoid collision and to ensure the motion of the final placement is perpendicular to the placement surface.

The module takes as input any number of 'destination' and 'source' tile positions modeled as Rhino surfaces. The module can accommodate stacked source tiles by inputting the number and thickness of tiles at each source position. The script then automatically identifies and matches every destination tile to its corresponding source tile stack. The program keeps track of the number of tiles in each stack and adjusts the elevation of the suction gripper accordingly. Multiple stacks can also be defined. In this case the module will direct the robot to source each tile from the stack of the right type until the stack is empty, at which point an alternate stack is chosen. If no stack information is provided the script assumes the source location is 'infinite', meaning that tiles are replenished every time one is removed. The robot will continue to revisit the same source location until the process is complete. Additional work object or backer board dimensions serve as input parameters that will universally translate all of the destination tiles vertically.

The module then outputs a text file written in RAPID code, the instruction language of ABB robots. This file can be loaded directly into the robot to begin the process. It is typically necessary to simulate robotic movements in the proprietary ABB software RobotStudio. In order to bypass this step and make the workflow seamless an inverse kinematic solver, previously developed by DRG contributor Panagiotis Michalatos, was used to visualize the robotic movements. This fourth module is independent and the robotic code can be generated separately if desired. However, the visualization of the robot movements within the Rhino environment greatly reduces the likelihood of error. Each file was simulated in both RobotStudio and the inverse kinematic solver to validate the tool.

Fig 3. Simulation of movement commands for one of nine tile sections within one panel of the image based Marilyn Monroe prototype.

APPLIED PROTOTYPE DEVELOPMENT
In order to better understand the parameters associated with robotic tile placement and its feasibility for the production of custom surface patterning a series of prototypes were completed using an ABB 4400 industrial robotic work cell and pneumatic suction gripper assembly.

Experimentation
Experiments were conducted involving dry placement of individual tiles at a prescribed location. The
final positioning was evaluated within machine tolerances through a comparison of the prescribed corner locations in the digital model and the actual corner locations of each tile using custom robotic tooling. Deviation in square tile placement was acceptable when accounting for actual dimensional variation within the tiles themselves. When using non-square rectangular tiles with the added complexity of a 90-degree rotation the impact of any calibration variation was exaggerated resulting in a slightly lower, but visually acceptable, accuracy.

Fig 4. Dry placement of tiles during early tests.

Pattern-Based Prototypes
Two prototyping exercises were conceived that utilized the previously mentioned pattern generation techniques to enable testing of the automated robotic tile placement workflow and address the calibration concerns above.

Prototype: Format Variation
Using patterns based on tile format variation a series of 7500cm² compositions were created from a combination of three different sizes of square and elongated rectangular tiles arranged using a 4mm grout line that was established to accept machine tolerances and dimensional inconsistency. A custom end effector was prototyped that incorporates a suction gripper assembly with a specialized housing designed to apply distributed force to the tile for 'placing' while remaining within the working range of the suction gripper for 'picking'.

During the initial series of prototypes certain physical limitations were realized. First, in a stacked tile supply the aggregate thickness variation within one stack of tiles often proved to be outside of the working tolerances of the existing custom tooling. Additionally the registration of the remaining stacked tiles was compromised as tiles were removed from the stack; as one tile was removed the tile below often shifted. These inconsistencies will be addressed during further tooling development.

Fig 5. Completed Marilyn Monroe image-based robotically placed tile pattern prototype.

Prototype: Image-Based Pattern
For the second prototyping exercise a tiled surface was designed using the image based patterning system that was divided into two panels to test the ability of robotically placed tiles to create multiple individual modular tiled surfaces that relate to a final assembly. In this example the iconic Marilyn Monroe image required 2247 individually placed tiles of dimensionally doubling modular square tiles ranging from 19.05mm to 173.4mm accounting. A final assembled dimension of 1530mm x 1830mm was constructed using two industry standard 12mm cement backer boards.

Two tile adhesion strategies were tested. On one panel slightly elastic tile mastic, and on the other a double-sided flexible tile adhesive sheet, was used. To accommodate for production time in the mastic-based sample, the pattern was divided into sections based on the set time of the adhesive. Periodic tiles were not included in the placement to allow for mechanical fastening during on-site installation; these voids would be tiled on site. The second panel utilized an adhesive sheet with an extended set time allowing the entire panel to be completed as one continuous process. More testing is needed to determine the best adhesive and backer board for a given scenario.

All tiles were placed robotically. The two panels were assembled and tile spacing was measured using previously described methods. Overall the grout lines remained consistent and only slight rotational
variation was observed. The resulting installation accurately represents the prescribed digital image and the face of Marilyn Monroe is readily recognizable thus validating the image-based design-to-robotic-tile-placement workflow.

EXPANDING ON THE STATE OF THE ART

The prototyped solution used affordable technology, employing an off-the-shelf factory-based industrial robot and widely available inexpensive software. Robotic tile placement requires the development of a new construction technique that allows tiles to be placed robotically in a location (factory) separate from the final installation (building or construction site) (Scenario A). Without significant advancements in on-site robotics, tiles could only be placed directly onto final and finished surfaces in the case of prefabricated construction (Scenario B). Issues for both scenarios are discussed in the following sections.

Construction Scenario A: On-site Installation of Factory Produced Modules

In this scenario tiles are robotically installed onto backer boards and then transported to the construction site for installation. The basic tile installation sequence would be as follows:

- After the tiling pattern is computationally generated the backer board subdivision is determined.
- Boards are labeled and an installation drawing is produced.
- Backer boards are cut using a CNC machine
- Backer boards are fixed in a jig or vacuum bed within the robotic work cell and an adhesive is applied.
- Tiles are robotically placed on the board.
- Each board is transported to a drying station while insuring limited deflection.
- The process is repeated for each board.
- Each board is labeled with a unique ID relating to the computationally generated installation drawing.
- Tiled boards are packed and shipped to site.
- An on site installer mounts the pre-tiled boards onto the rough wall or floor surface.
- Missing tiles for edges and surrounding fixtures are cut and installed by hand.
- The surface is conventionally grouted and finished.

Tile Backer Board

Material and Bonding Agent

The typical backer boards include cement backer units (also called CBU; ANSI A108.11, ANSI A118.9, ASTM C 1325), fiber cement backer board (ANSI A108.11, ASTM C1288), and glass mat water-resistant gypsum backer (ASTM C1278).8 Boards are usually 12.5 mm thick and come in standard formats around 0.9 m x 1.5 m. The choice of backer boards determines the substance needed to bond the tiles to the board. Latex/polymer modified Portland cement mortar, and epoxy are recommended options for all three boards. Dry set mortars are an option for CBU, while organic adhesives present another option for the other two board types. High quality bonding agents are key in preventing tiles from falling off, cracking, or partially de-bonding from the backer board.

Backer Board Size and Deformation

Based on the maximum allowed U.S. lifting weight of 13.6 kg (30 lbs, overhead) to 18.1 kg (40 lbs not overhead)9 the maximum size of a typical pre-tiled concrete backer board would be 0.46 – 0.65 m² (5 to 7 ft²) when installed by one person, and twice that amount for a two-person team. Size limitations will also depend on the panel flex and the risk of tile breakage. According to a report by the Ceramic Tile Institute of America, Inc., tile floors installed over wood joist systems can deflect up to 11.4 mm (0.45 in.) over a span of 4.06 m (13.33 ft) without risk of cracked floor tiles.4 Extrapolating that data, and assuming a backer board segment 1.20 m (4 ft) long, the sheet could deflect by 3.3 mm (0.13 in.) without risk of tile cracking. The maximum permissible deformation depends to a large degree on the tile format, the material used as the backer board, and on how boards are stored, transported, and handled on site. A computational deflection study (assume concrete backer board with f_c = 20,684 kPa or 3,000 psi and 9 mm or 3/8 in. tile surface with tiles measuring 50 by 75 mm, placed with 4 in grout joints) of a board measuring 1.2 m x 0.45 cm (4 x 1.5 ft), carried by two people in the long direction showed 9 mm (0.35 in.) of deflection from dead load.

Backer Board Cutting

Water-jet cutting would be a cost-effective method of trimming backer boards to a size that matches the tile pattern. Using an automated tool changer water-jet heads could be mounted on the same robot used for tile placement, as is currently done at Harvard’s robotic work cell.

Robotic Tile Placement Technique

When installing tiles by hand it is recommended to beat them in gently using a beating block or a rubber mallet, ensuring the back surface of the tile fully adheres to the bonding agent. Further research is needed to determine the appropriate robotic techniques for achieving the same effect. Force sensors at the robotic end effectors can be configured to apply tiles with even pressure, potentially improving the consistency of installation compared to manual installation.
Backer Board Mounting

Backer boards with pre-installed tiles need to be installed on site using commonly available techniques. Adhesives, mechanical connectors, and combinations thereof are possible. Backer boards are normally screwed directly into the studs (wood or metal stud construction) or bonded with thin-set mortar onto masonry or concrete walls. Mechanically connecting into the studs is not feasible for pre-tiled backer boards because tile patterns and stud patterns will rarely align. Backer boards should thus be adhered to another surface – a layer of sheet wood or concrete board in the case of stud construction, or directly to the wall surface in the case of masonry construction.

In manual tile installation a gap of 2-3 mm is recommended between adjacent backer boards, normally to be filled with mortar and taped to prevent water penetration. In the case of the pre-tiled system moisture barriers would be applied onto the surface behind the pre-tiled backer boards. Backer boards can be cut such that a slight gap, the size of the grout joint, remains between boards in order to allow for adjustments in response to normal construction tolerances. Total system thickness for stud construction will increase by approximately 12.5 mm because pre-tiled backer boards require an initial board to be installed onto the studs.

Scenario B: Direct Robotic Placement during Pre-Fabrication

In pre-fabricated construction tiles can be installed directly onto a surface prepared by other trades. The following process would apply:
- The tile surface is prepared in accordance with the standards of the adhesive.
- Adhesive is robotically applied to the board surface.
- Tiles are robotically placed onto the surface.
- Once the tile bond dries the surface is conventionally grouted and cleaned by hand.

Edge and Adjustment Tiles

The realities of construction will usually require a certain number of tiles to be cut to fit around fixtures or to make up the distance between the regular tile pattern and the edge of the surface. For Scenario A the cut tiles will be mounted on-site prior to grouting, for Scenario B the cut tiles can be installed directly in the factory. In the future it may be possible to pre-cut most odd shaped tiles based on as-built laser scans of the surface to be tiled.

FINANCIAL FEASIBILITY STUDY

Using the prototypical panel described the approximate costs of robotic tile placement based on current U.S. industry standard labor and robotic machine rates are as follows:
- $86 – $110/m² for standard tile patterns
- $270 – $430/m² for mosaic tiles pre-mounted on 30 x 30 cm sheets

*Average manual tile installation cost including edge trimming and grouting. Tile installation costs can vary based on location; New York City for example can be more than twice as expensive, while rural areas will have significantly lower costs.

Comparatively robotic machine time including 1 operator is $120 / hr including all overhead. The prototype measures 2.78 m², and features a total of 2,247 tiles of four different designs. The study assumed several robotic placement rates determined in both computation simulations as well as derived from the experiments at the GSD. These placement rates were 7, 10, and 12 seconds on average per tile. Setup time for the panel was estimated at one hour in a professional production context. On-site installation of the pre-tiled surface was assumed to take 2 man-hours, and grouting was estimated at 3 hours. The comparative calculation assumed the above mentioned manual tile installation costs. The cost rates quoted assume net-mounted mosaic tiles in 30 x 30 cm sheets. Rates for complex patterns such as the one enabled by robotic tile placement are not available, but can be estimated to be much higher.

The study shows that robotic tile placement could be competitive as far as installation costs are concerned. Within the range of placement parameters (both robotic placement rate and manual installation costs) the cost for an installed square meter of tiled surface is in the range of $380–540 for both robotic and manual methods. Given the added value of customizing the tile pattern for robotic placement it seems clear that the technique would be feasible in practice from a cost point of view.
Estimated Capital Costs
Investment costs for a robotic tile placement cell designed to run constantly for 5 years on average are estimated to be in the range of $100,000 to $200,000. The software needed to run the cell is extremely low-cost, the commercial retail value of the package at present being $1,000/seat without the additional digital tools developed by the GSD research team.

Future Developments and Outlook
Format customization as an added opportunity remains to be explored as a next step. Format customization could be seen in the following contexts:
- Tile formats are customized on certain production lines allowing a wider range of placement patterns.
- Customization may take into account as-built dimensions of walls and floor surfaces, creating customized tiles that eliminate or drastically reduce on-site cutting waste. Laser scanning as-built surfaces would allow the integration of precise geometry data into the pattern algorithm.
- Tile patterns using leftover tiles, creating value by using unwanted products. Cutting leftover tiles is also possible to avoid format limitations.
- Stochastically generate tile patterns based on broken tile (tile trash) from factories or sites where tiles are installed in conventional ways.

Next steps in the technology development include improving the user interface of the computational pattern generator, as well as a possible web-based interface. Refined custom robotic tooling could be developed using force-sensing and other technologies as agents of quality control.

Conclusion
The need for tile customization is growing, as the success of ink-jet printing on ceramic tiles in Spain is demonstrating. The potential market would likely be medium to high end consumer and commercial, but also infrastructure and transport (e.g. subway stations etc.) applications.

The research studied the potential for robotic placement of industry-standard pressed tiles using a computational workflow that allows complex patterns to be created based on a variety of mathematical algorithms and image based methods. The generation of machine code, process simulation, and ultimately robotic tile placement can be automated using the proposed integrated design-to-robotic-fabrication workflow. Several initial tests were conducted to determine the feasibility of the technology.

A final prototype measuring 1.8 by 1.5 meters was produced as a proof of concept, demonstrating that the novel technology can indeed be employed to produce complex tile patterns impossible to install economically by hand. An initial cost comparison shows that installation costs for both robotic and manual placements are similar, but robotic methods can produce highly varied, custom patterns.

Acknowledgments
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Towards Robotic Assisted Hygienic Services: Concept for Assisting and Automating Daily Activities in the Bathroom

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Purpose Elderly people use competencies necessary to perform Activities of Daily Living (ADLs)1 in the following sequence: 1. Bathing, 2. Dressing, 3. Toileting, 4. Transferring, 5. Continence, 6. Feeding. Although bathing is a basic ADL, only a few approaches have tried to establish advanced assistive technology for this field. In the proposed research a basis for introducing automation and robotics for bathing activities was developed. Method Bathing can be divided into a multitude of subactivities which have various relations to each other2. In our research we have identified those subactivities as well as usual course of activity (activity chains). In order to identify sub-activities which can or should be automated the bathing activity was analyzed (course of activity, time needed to perform sub-activities, problems etc.) of several persons of different ages. Based on this research concepts for partially and fully automated bath environments were explored. This exploration design was performed systemically as follows: i) research and identification of needs, ii) definition of requirements, iii) identification of technologies and processes, iv) initial concept, v) experiment in real environment, vi) final concept and further development roadmap. Results & Discussion The concepts developed for configuring a robotic bath show that, it is basically possible to automate a sequence of subactivities in the bathroom. However, there remain many open questions: What degree of automation is suitable for which kind of person? Can safety issues, especially in the bathroom, be met by an automated bath? Can the system be modularized in order to meet the requirements of different room layouts?

Keywords: ambient integrated robotics, daily living activities, demographic change design

INTRODUCTION
Caring for elderly people is becoming increasingly important. Originally, children took care of the older generation, but this changed especially in industrial countries. In China and Japan children used to care their parents as they entered old age. Nowadays, this practice often is no longer followed. Additionally, the care system in many countries varies, contributing more or less to the ageing society. For example in China, there is no global state care system establishment. Only 1% of the 80+ generation is found in private health care facilities. The ageing society is required to cover its own caring expenses in private facilities. Nowadays, the majority of the population worldwide focuses more on their professional career, rather than to the family3, 4. That means not only that people increasingly pass on the responsibility of caring the elderly, but also a lower birth rate is recorded. Since the young generation is gradually decreasing, demographic change5 is increasing at a rapid rate, and therefore the definition of a strategic approach efficiently dealing with this problem becomes even more essential. A demographic change measure within the past century and an estimated growth in the next 20 years in Europe is presented in Figure 1.

Fig.1. Projected demographic change in Europe

RESEARCH AND SURVEY
Activities of Daily Living (ADLs)6 represent the everyday tasks people usually need to be able to independently accomplish. ADLs can be grouped in two main categories: a) Basic ADLs (BADLs) and b) Instrumental ADLs (IADLs). BADLs7 consist of self-care tasks, including: personal hygiene, grooming, dressing and undressing, self-feeding, functional transfers (getting into and out of bed or wheelchair, getting onto or off toilet, etc.), and mobility (walking without using an assistive device such as walker,
cane, crutches, or wheelchair). More complex skills are defined as IADLs. IADLs are not necessary for fundamental functioning, but they let an individual live independently in the community. IADLs include housework, taking prescribed medications, managing money, shopping for groceries or clothing, use of the telephone or other form of communication, using technology (as applicable), and transportation within the community.

BADLs such as bathing, dressing and eating, can be used as a basis for assessing the independence of the ageing society. Older people tend to require even more assistance in performing BADLs, requiring thus the constant presence of an extra caretaker, i.e. they are care dependent. A representation of the required assistance in BADLs according to different age groups can be seen in Figure 2. Considering the demographic change projection depicted in Figure 1, it can be easily noted that this assistive service reflects to a very small fraction of available population age groups, which gradually becomes even more negligible, due to the evolving demographic change.

The daily routine of elderly people is often accompanied by functional challenges. Even, simple tasks sometimes require human assistance. In order to enhance the independence of elderly people numerous assistive devices and technical aids have been developed. Designers often focus on simplifying hygiene tasks, because the sense of shame is very high in these situations. For example, to adapt the height of the toilet seat an add-on riser can simply support older people to stand up from a sitting posture. Similarly, the shower ought to be designed barrier-free in order to easily adapt in various situations. Problems addressed during showering include severe injury risks from slipping and fatigue induced by prolonged standing. Additionally, a wide range of various waterproof chairs exist in the market. These are often foldable and have additional features to enable a comfortable bathing process. Figure 2 depicts some of the aforementioned aiding devices.

An extended problem is the bathing process. The arrangement of a standard bathtub, introduces a series of difficulties to elderly people. Its heightened side edge is often a challenge for elderly people. They do not have the physical strength to independently enter, sit down and stand up in a bathtub. To overcome these limitations designers created “walk in tubes” or developed chairs with an electric lift function to compensate the height difference (Figure 4).

The disadvantages of the aforementioned approaches and solutions presented in Figures 3 and 4, concern the fact that in many cases the presence of an assistance is required, either to supervise the whole procedure or to assist on the deployment and operation of the assistive device. Their contribution in increasing independence for the ageing society in BADLs is clear, but the proposed research aims to optimize and enhance even further this independence factor, by configuring the environment of the individual in order for the functions and services to come to the user, than the other way around.

**EXPERIMENTS**

To optimize the bathing environment and identify needs and difficulties of hygienic processes, a behavioral analysis was followed. Eight individuals of
different ages were evaluated and the required time fulfilling the bathing process was recorded. Table 1 presents the corresponding evaluation results.

Table 1. Bathing time requirement evaluation results

<table>
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<th>Person</th>
<th>Age</th>
<th>Sex</th>
<th>Bathing time (minutes)</th>
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<tr>
<td>1</td>
<td>23</td>
<td>Female</td>
<td>6.3</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>Male</td>
<td>4.7</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>Female</td>
<td>9.5</td>
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<tr>
<td>4</td>
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<tr>
<td>8</td>
<td>85</td>
<td>Male</td>
<td>14.2</td>
</tr>
</tbody>
</table>

Additional tasks were evaluated by the 8 individuals during the experiment. According to the person sex, the following tasks were performed.

- Remove clothes
- Using toilet
- Brush teeth
- Shower
- Hair washing
- Shave
- Hands washing
- Dry off
- Hair styling
- Blow drying
- Cleaning ears
- Dressing
- Facial wash
- Putting Lotion
- Make up
- Wash with washcloth

Fig. 5. Evaluation tests

RESULTS

The evaluation experiment confirmed that elderly persons require much longer time to perform most subjected tasks, Figure 6. Although the combinations of the tasks differ for each person, some tasks are performed by all and the order of them is the same, i.e., taking clothes off, showering, drying off and dressing. It is noticeable that the oldest person needs a shorter time to accomplish the series of given tasks than the average does. This is because in that case the person is not independent and another person was required to wash the older person with a washcloth, requiring therefore less time than an independent test person.

The results can be summarized in three main identified points:

- Usage vs. layout: scattered processes and long distances between every “station”
- Agility: physical agility decreases in old age and complicates the daily routine
- Mobility: Confined spaces affect domestic mobility

Fig. 6. Overall time required to accomplish all subjected tasks

CONCEPT

After defining the processes existing in the personal hygiene and grooming, it is possible to define a concept for an optimized bathroom environment. Emphasis is given to efficiently address mobility issues in confined spaces. Nowadays, space within the home environment is a luxury only for a very small fraction of population groups. The layout of the average family houses in Europe ranges around 60 m². Thus, the free space must be exploited to its limits in order to allow enough space for mobility. The future bathroom should be compact and user-friendly.

The proposed concept combines the functions in order to enable a novel process flow adjustment. The main idea is to fuse various technologies and robotic elements, in order to enable a novel scheme of processes flow, while performing BADLs. The term ‘process flow adjustment’ refers to the proposed automated bathroom environment, which adjusts in a novel manner the process flow, while performing BADLS. The processes flow of BADLs, in case they are performed in a regular residential environment, significantly differs from the processes flow offered by the proposed automated environment, due to the fact that the processes are fused in a single cell, allowing the BADLS to be efficiently performed.

In Figure 7, a process combination scheme is depicted. An automatic “bathing machine” for people can offer the ability of automate the bathing process reducing the time and the effort needed. An arrangement of a drivable toilet, allows an accordingly customized mobility assistive device such as a wheelchair, to dock to the toilet and allow a straightforward transfer, without requiring excessive physical strength. An embedded cabinet system, attached to the outer wall of the shower cabin, serves as a discrete storage space, in accordance to reduced space demands. A functional wall embedded behind the mirror of the bathroom, offers services such as measuring and display terminal of user’s vital signs, tele-care and tele-consulting, communication medium, etc. A mobility assistive wheelchair, specifically
designed to adapt to the various function of the bathroom environment, offers conformity, ease of use, contributing in enhancing the independence of elderly people in performing ADLs.

Fig. 7. Process combination scheme

The concept addresses the general configuration of the apartment. The layout must be flexible, as well as individual. The bathroom concept and the kitchen with its appliances should be the only fixed functions in the room and all interior walls should be eliminated. This enables a barrier-free arrangement of the apartment.

Fig. 8. Apartment transformation to barrier-free arrangement

**SOLUTION APPROACH**

The idea for the futuristic bathroom is to divide it into three sections: the shower room, the toilet and a functional wall with washbasin. The shower room comprises a “bathing machine” that has water nozzles attached to the sides, which spray water as well as shower gel. Integrated blowers dry the user with hot air after showering. The washbasin is height-adjustable like the storage cabinets and shelves attached to the outer wall.

Fig. 9. Proposed bathroom environment

Additionally the electrically driven wheelchair provides mobility to each station of the proposed bathroom environment. The wheelchair was specifically designed to be compatible and adaptive in order to dock with the toilet. The wheelchair seat can be raised to various elevation levels according to functional requirements. The proposed wheelchair aims to allow the user to move easily into all possible areas of the bathroom environment, and at the same time be used in most of the performed activities without requiring the user to repeatedly transfer to different locations.
CONCLUSIONS

An approach towards robotic hygienic assisted services focusing on the global demographic change problem is addressed in the proposed research. Elderly people tend to require assistance in performing basic ADLs. The demographic change prediction though, reveals a disparity in having younger people to continue to contribute in assisting elderly people, while the younger generation is diminishing in numbers over the recent years. Eventually, a great number of elderly people are going to face the consequences of this demographic transformation in their everyday living.

It is therefore important to try and increase the independence of elderly people in ADL performance. The functions and procedures need to be automated in order to allow their unattended accomplishment. Technologies need to be combined with architectural approaches, in order to provide fully optimized and modular solutions, efficiently addressing the various tasks.

The proposed approach dealt with identifying the needs and requirements by conducting a survey among various age groups and identifying the main bottlenecks and limitations. A design procedure was then proposed in order to provide an efficient solution in optimizing hygienic services in the home environment while increasing the independence of elderly people in the corresponding ADLs.

The proposed concept comprises the combination of robotic and architectural elements, aiming at the realization of a novel robotic bathroom, which in combination with a specifically designed compatible robotic wheelchair can efficiently address mobility issues elderly people face, simplifying hygienic services and minimizing the existent injury risks that commonly occur in such situations.

References

Co-adaptation of Assistive Mobility Devices and Residential Functions

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Purpose For facilitating an independent living for elderly or disabled people, a method has been developed at TUM Building Realization and Robotics Lab, which aims at creating intelligent living environments by adjusting mobility systems and everyday objects (e.g. appliances) as modular and complementary subsystems. The proposed system comprises an intelligent wheelchair, which enables simplified use of the bath-room, kitchen and living room, etc. It can dock at certain functions, e.g. the toilet, both on a physical and information technology level. Method Studies show that the major problem for people with physical and/or cognitive disabilities in everyday routine and in managing the Activities of Daily Living (ADLs) is the surmounting of different height levels and distances. Even for a person with a good physical fitness, it is extremely difficult or even impossible to transfer from a wheelchair onto a couch autonomously. The reason is the height difference between the furniture and wheelchair, as well as the space or gap that occurs mostly between the transport device and the piece of furniture. The proposed work presents a thorough research study, which enabled a huge gain in knowledge, concerning the re-design of household appliances and devices, in order for them to be straightforwardly and cost effectively integrated with mobility supporting robots. The outcome of this research, led to the participation on a research project which involves 7 companies and 3 universities. In order to realize the co-adaptation of an assistive mobility device and residential functions, the following development approach steps were followed: i) research and identification of needs, ii) definition of requirements, iii) identification of technologies and processes, iv) initial concept, v) experiment in real environment, vi) final concept and further development roadmap. Results & Discussion Most wheelchairs are designed with a fixed height and do not provide features for altering their elevation level. Additionally, handicapped individuals face major problems when reaching items located higher, due to the fact that objects in the environment are mostly located statically, and it is difficult to get at them as a disabled user. Especially for disabled people, the functions should come to them instead of the other way around. The results of the study prove that the co-adaptation of assistive mobility devices with various residential functions, allow the complexity reduction of mobility robots. Companies notice a huge potential in such an approach, as it would allow them to design less complex, and thus more cost effective robots for ADLs use. The high cost of robots is currently one of the main obstacles for deploying them in the home environment. Based on this study, TUM was finally able to set up a government funded 3-year R&D project (total funding cost: 3.9 Million €, starting from June 2012) where major strategies, processes and components necessary to achieve uninterrupted mobility chains for elderly people will be brought to product market level.

Keywords: mobility & transport, ambient integrated robotics, assistive mobility, demographic change design

INTRODUCTION

The current world population comprises more than 7 billion people. This figure increases enormously, although the population in industrial countries is declining. In contrast to developing countries the consequence in industrial ones is demographic change, Figure 1. This means that the population is aging over time, reducing the fraction of the population in working age. This process is driven by falling mortality rates followed by a decline in birth rates, which reduces population growth rates (and even turn them negative in some countries). While demographic change occurs in all countries worldwide, extent and timing differ substantially. Europe and Asia countries have almost passed the closing stages of the demographic transition process while Latin America and Africa are only at the beginning. The older population’s stratum becomes more and more important to focus on. This study deals with a way to assist old age people. The first phase of the project comprised research on activities of daily living and the state-of-the-art technologies. That was followed by experiments to find out difficulties. These difficulties were analyzed and assessed. The results of this procedure influenced the concept which can be divided into architectural, social and network part. Finally an interesting solution approach was proposed.

RESEARCH AND SURVEY

Activities of Daily Living (ADLs) represent tasks in everyday living, that people usually need to be able to manage as independent adults. Basic ADLs (BADLs) consist of self-care tasks, including:
personal hygiene and grooming, dressing and undressing, self feeding, functional transfers (getting into and out of bed or wheelchair, getting onto or off toilet, etc.), ambulation (walking without use of an assistive device such as walker, cane, or crutches, or a wheelchair). More complex skills are defined as Instrumental Activities of Daily Living (IADLs). IADLs are not necessary for fundamental functions, but they allow an individual to live independently in a community: housework, taking prescribed medications, managing money, shopping for groceries or clothing, use of telephone or other form of communication, using technology (where applicable), transportation within the community. The defined routine tasks, such as bathing, dressing and eating, can be used as a base for assessing the independence of elderly people.

Difficulties are often introduced in subsequent developments for supporting and assisting the ageing society. Even if the technology assists and supports the daily living in an optimum way, the technology acceptance is negligible by the majority of the elderly individuals. Either due to the purchase costs, or to the technological complexity involved in these products, which makes them difficult to be managed and operated by an old person. A wide variety of wheelchair designs already exists in the market (Figure 2).

Some are more realistic and others are more futuristic. Several designers try to find different solution approaches for diverse problems. Thereby, a wheelchair should guarantee the best possible freedom of movement.

Also the Toyota automotive manufacturer company, which is dealing with the issue of mobility, developed supporting systems called Welcabs. The main idea behind Welcabs was to assist elderly and disabled people to easily get in and out of a car. The implemented designs differ from additional ramp to movable car seats (Figure 3).

Nevertheless, one of the main challenges ageing society is facing, is not only to get in and out a car, but the functional transfers like getting into and out of bed or wheelchair, getting onto or off toilet (Figure 4), etc.. An approach to solve this problem would be either to adapt the environment arrangement to the specific functional transfer needs, or to optimize the wheelchair design and features. The optimal solution though is to find a combination utilizing both these two alternative approaches.
Experiments
Locomotion with a wheelchair restricts the everyday life in a great extent. Normal routine tasks like getting into and out of bed comprise a challenging process. Therefore experiments were conducted dealing with functional transfer issues in order to identify the difficulties and limitations involved in these processes.

Living room
A typical living room problem elderly and impaired people are facing, is to transfer from the wheelchair onto a sofa. The experiment shows the existing height difference these people have to compensate when they want to sit down on the sofa. Additionally, even if the sofa and the wheelchair had the same height level, it is impossible for someone to transfer to the sofa without the assistance of a second person, considering the arrangement depicted in Figure 5.

![Fig.5. Living room sofa-wheelchair transfer](image)

Kitchen
The furniture in a standard kitchen have standardized dimensions, in order to comply with global standards that were predefined to allow the installation of universal size appliances such as electric stoves, fridges, dishwashers, etc.. Without any adaptations for wheelchair users, there are a lot of disadvantages identified by the experimental procedure. According to Figure 6, restrictions and limitations are introduced when retrieving items from the shelves or want to use the tap and the sink.

![Fig.6. Kitchen environment issues](image)

Dining/Working room
The last part of the experiment was to define the limitations wheelchair users are facing while approaching a dining table or a working desk (Figure 7). Once more it was observed that it is impossible to approach close enough to the table area, due to restricted height dimensions, since the wheelchair does not fit under the given height. One might say that this problem can be easily overcome by increasing the demanded table height dimension. The disadvantage this solution imposes is that instead of adapting the wheelchair structure to most of existing table heights, in order to enable compatibility to many different situations, the table is adapted to the given wheelchair, implying thus a unique solution that cannot be applied to more everyday activities.

![Fig.7. Dining room/Work room](image)

Results
The conducted experiments allowed a series of observations and conclusions. The major problem identified though, is the different dimensions existing between wheelchair height and the test subjects. Table 1 indicates the aforementioned problem.

Living room
The executed tasks seem to be impossible to be perform by old people sitting in a wheelchair. The distance between sofa and wheelchair is too wide and additionally a great height difference also exists. A further obstruction is also the armrest of the wheelchair. Since the armrest is not foldable the wheelchair couldn’t be placed ideally along the sofa. Even with enormous efforts it seems to be impossible to transfer to the sofa.

Kitchen
The heights of the shelves and accessing the kitchen worktop can be a problem for the corresponding individuals. Wall cupboards are almost impossible to be used. The main difficulty observed while using the
kitchen worktop is that there isn’t usually any free space under it to place the wheelchair.

<table>
<thead>
<tr>
<th>Area</th>
<th>Action</th>
<th>Difficulty level</th>
<th>Accident risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>Sofa / Bed Wheelchair</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Sofa / Bed Wheelchair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>Shelf height: 10 cm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>45 cm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>80 cm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>&gt; 125 cm</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>&gt; 160 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sink</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Water tap</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kitchen worktop</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Dining/Working Room</td>
<td>Move the wheelchair towards table</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Move the wheelchair away from table</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eat and work</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Dining/working Room
Since the wheelchair cannot be, in most situations, fitted under the table top, (unless using a relatively higher table), difficulties are introduced in case the individual requires to either eat or work efficiently using the table or desk area.

CONCEPT
Using the results obtained from the various experiments conducted, a mock-up for an optimized wheelchair was designed and a concept was realized. The concept can be divided into three parts: architectural, social and networking concept.

Architectural concept
In a standard apartment there are several rooms, each of them with different functions. Some rooms are hardly ever used, mainly because the different height levels often constitute a challenge. The function of the room can be structured and summarized. Functions with installations, such as kitchen and bath, are integrated together eliminating the existing separating walls in between. By placing functions together, a type of cell structure is introduced. Thereby this cell is built as a modular system and can be individualized. An important issue is to design and implement a cell fusing most of the apartment functions, while leaving the rest of the apartment barrier-free, in order to be unrestrictedly used by a wheelchair user. In Figure 8, the proposed architectural concept is presented, where the motion analysis depicted paths, prove that a centralized function cell, reduces the required transport needs of the impaired user.

Networking concept
Nowadays, networking undoubtedly comprises a necessary service. Optimized networking systems offer enhanced service delivery, extend the communication barriers, and improve quality of living. Databases and information exchange platforms, enable access to various kinds of data, either from defined places or user defined terminals, while presenting the feature of data synchronization on different appliances and devices. The aim is to integrate such platforms in the proposed cell structure and also connect them to services, for example tele-care, domestic aid, security, and infotainment. This can contribute in enhancing the quality of service delivery to isolated elderly or disable people, and assist them in discovering new possibilities and ideas.
Social concept
Especially for elderly people the social connection is an important missing option of their daily routine. Elderly people spend more time in their home environment, either due to disabilities or to health condition issues. Communication with their social network is explicitly achieved over the telephone, which is a very limited, in terms of features, type of communication. Nowadays social online networks are more common and more integrated. Elderly people on the other hand, are not very familiar using the World Wide Web. It must be noted though, that today’s young generation comprises the senior generation of the future. Thus the existing technologies ought to be adapted to this situation. However the physical social networking is not negligible as well. Approaches should be proposed on how to design the ground plan for apartments addressed to elderly people. Two main types of areas are proposed: private and public ones. A harmonic combination of these types could affect in a positive way the daily routine of elderly people (Figure 9).

SOLUTION APPROACH
The proposed concept aims to implement a modular system which is an optimized combination between a wheelchair and fixed installation modules. Unnecessary partition walls will be removed, allowing only the main cell to dominate the area fusing main functions of ADLs like eating (kitchen) and bathing (bathroom –toilet). Furthermore, the specially designed wheelchair enables the best possible mobility within the area, while at the same time communicates in an informational level with the cell, in order to exchange data acquired by its built-in sensors. The proposed concept is depicted in Figure 10.

The cell installation could be designed as a core of the apartment. It is the main part of the concept and contains most of the functions assisting in ADLs. It supports the independence of elderly people with optimized furniture and shortened transition paths. Due to its modularity, the cell can be individualized according to the user needs, or even upgraded.

Fig.9. Social Concept

In the centre, there is the personal hygiene and grooming area, i.e. toilet and bathroom (Figure 11). Depending on the user it can be equipped with a standard toilet and bathtub/shower, or considering a wheelchair user it can be equipped with an optimized toilet and shower. A central rotating platform mechanisms embedded in the floor, supports the mobility of a wheelchair by rotating the user accordingly to the desired function in the bathroom. An integrated communication platform, allows data exchange between the different available services. For example the vital signs data of the user, measured by the inbuilt sensors of the wheelchair, could be sent to a physician for a remote checkup.

Fig.10. Proposed concept

Fig.11. Functions of the proposed concept

The wheelchair consists of three main components: the substructure, the central axis and the seat. Extensive attention was given on the transfer of the individual between the wheelchair and the cell elements. To reduce the user efforts the chair is motorized offering a lift function. The most important component is considered to be the seat and the armrest with the built-in sensors. The collected data are sent using WiFi technology to the cell communication platform, where they are accumulated and stored.
These can then be evaluated by an expert and / or retransmitted back to the cell.
The majority of the embedded sensors comprise vital sign measuring devices that are embedded on the wheelchair in order to seamlessly acquire readings. A respiration frequency meter, a weight analysis meter (measuring BMI-index), a Electrocardiogram sensor (EKG), and activity logger sensor on and around the chair, and a infrared pulse oximeter (to monitor oxygenation of user hemoglobin), are integrated in the chair’s vital sign sensor features. These offered features are presented in Figure 12.

The proposed research and realized concept formed a basis in creating a multidisciplinary consortium, involving academic and industry partners, leading to a research project in the field of Ambient Assisted Living (AAL) called PASSAge. PASSAge is a 3 year BMBF-funded R&D project (June 2012 – June 2015) with a total cost volume of 3.9 Million €. Besides the authors, 9 other academic and industry partners form the consortium. The concept described in the proposed paper, are going to be further developed and finally implemented during the research project duration. The involved industry partners, such as Streifeneder11, are already active in implementing products and assistive mobility devices focusing in disabled individuals, Figure 13.

**CONCLUSIONS AND FUTURE DEVELOPMENT**
The proposed concept addresses the mobility issues within the ageing society by developing a modular and personalized mobility system that can be integrated into the individual surrounding of the user, enhancing the quality of everyday living by encouraging individual mobility, as well as providing safety, comfort and health. Adaptable, customizable and user-friendly add-on modules (operation and shopping assistance, health phones, transfer support at the entrance of buildings or within buildings) are being adapted by existing technologies and innovative mobility components from the field of personal mobility devices (e-bike, e-rollers, e-car, trolleys), which are already equipped with various technologies (ICT, micro-systems). The concept aims to implement a modular system which is an optimized combination between a wheelchair and fixed installation modules. A co-adaptation of assistive mobility devices with various residential functions is proposed, allowing thus the complexity reduction of mobile robots. Companies notice a huge potential in such an approach, as it would allow them to design less complex, and thus more cost effective robots for ADLs use. The high cost of robots is currently one of the main obstacles for deploying them in the home environment.

**Fig.12. Proposed Wheelchair embedded sensors**

**Fig.13. Intelligent wheelchair assisting in functional transfers**

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Modeling of a Mobile Manipulator for Redundancy Resolution

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Purpose
Recently, various applications of robotic systems to construction sites have been tried. In this research, a mobile platform-based serial manipulator, the so-called ‘mobile manipulator’, is employed for construction tasks such as material handling, beam assembly, welding, and so on. Generally, a serial manipulator has 6 DOF (degrees of freedom). The mobile manipulator suggested in this paper adds 2 or 3 DOF, so that there are a total of 8 or 9 DOF. In 3-dimensional space, the minimum DOF for manipulation is 6. A manipulator that has more DOF than 6 is called a manipulator with ‘redundancy’. While a manipulator with redundancy like the proposed mobile manipulator has several advantages such as large flexibility, singularity avoidance, easy obstacle avoidance, and so on, the redundancy resolution for optimal manipulation is not easy. In this research, modeling of the mobile manipulator for redundancy resolution is studied.

Method
Since the suggested mobile manipulator is a MIMO (multi-input multi-output) robot system with 8 or 9 links, a state-space model is derived for redundancy resolution. Analysis of kinematics and dynamics for a serial manipulator and a mobile platform is performed. An integration of the serial manipulator and the mobile platform is used.

Results & Discussion
In this research, a state-space model for the proposed mobile manipulator is derived. This model enables redundancy resolution for optimal solution of 8 or 9 DOF-robot system. In order to solve the redundancy resolution problem, a linear quadratic method, which is one of the conventional optimal control methods, or a reinforcement learning method can be used.

Keywords: mobile manipulator, redundancy resolution, construction robot

INTRODUCTION AND PRELIMINARIES
Modern robot systems have broadened their working capacity and application areas by fully or partially automating industrial systems, especially manufacturing, assembly, palletizing, and so on, or cooperating such tasks with laborers. So far, robotic systems have been dominated by serial-typed manipulators with a fixed platform. However, as working process and configuration had been complicated and the types of tasks had significantly increased, conventional manipulatory process which had been performed on a fixed base encountered a marginal situation in aspect of cost and productivity. Recently, a novel manipulatory alternative has appeared, whose name is mobile manipulator which combines a robotic manipulator with a mobile platform. It contains a mobile capacity so that it moves several working sites and extends the working space of the manipulator infinitely. Palletizing process of huge elements such as Flat Panel Display (FPD) is one of the representative applications of the mobile manipulator, where a serial manipulator for panel handling is combined with a longitudinal mobile cart for transferring the manipulator and the panel. Highway crack inspecting and sealing robot is another example of the mobile manipulator. It has a gantry-typed Cartesian manipulator with end-effectors for inspection and crack sealing, and a wheeled mobile platform which transports the manipulator. An unmanned excavator is also a mobile manipulator which is being largely used in construction fields. It joins a hydraulic serial manipulator with a caterpillar or tracked mobile base.

This research deals with a wheeled mobile manipulator (WMM) which combines a serial manipulator with a wheeled mobile platform. Generally, a serial manipulator which is operated in a 3-dimensional space has 6 degrees of freedom (DOF). A wheeled mobile platform has 3 DOF since it can generate a translational and rotational motion in a plane. Therefore a general mobile manipulator which combines two devices listed above comes to have total 9 DOF. However in a 3-dimensional space, only 6 DOF are required to uniquely and perfectly define a motion or a pose of an object. The general mobile manipulator which has 9 DOF contains 3 surplus DOF in aspect of generating 3-dimensional motion. It is called so-to-speak a manipulator with redundancy or a redundant manipulator.

A system with redundancy such as the WMM has several advantages. First of all, it has a large flexibility to generate a desired motion of an end-effector since it has a variety of candidates of solution for a motion or a pose. It is advantageous to avoid obsta-
cles with the surplus DOF. It is possible to evade a
singularity which makes the manipulation unstable.
Generating a desired motion by operating a 9 DOF
system in 3-dimensional space, where only 6 DOF
are need to define a motion, there exist not a unique
solution but an infinite number of solutions due to the
surplus DOF. To choose or find one solution which
is optimal to performance requirements among infi-
nite solutions which exist in a redundant system
problem is called redundancy resolution.

In this paper, a state-space modeling of a WMM is
performed, which is a preliminary work to redundan-
cy resolution of the WMM. Due to complexity prob-
lem, instead of the general 9 DOF WMM, a reduced
manipulator which consists of a differentially driven
wheeled mobile platform with two wheels and a re-
duced serial manipulator with two links and two revo-
lute joints. It is quite straightforward and tedious to
expend the reduced WMM to the general system.

Firstly, in this paper, a kinematic modeling of the
WMM is conducted, which considers only the motion
of the system. Then, a dynamic model of the WMM
is derived, which deals with both the motion and
force of the system. Finally, concluding remarks and
further research topics are mentioned.

**KINEMATIC MODELING OF WMM**

Fig. 1 shows a schematic diagram of a WMM which
is the target system of this research. A body fixed
frame \( \{xy\} \) attached on the mobile platform is a local
coordinate system whose origin is located on the
center of mobile platform mass and represented by
\( R \) in terms of a global coordinate system \( \{XY\} \). The
mobile platform is transported by two independently
driven wheels attached on both sides. The distance
between the center of mobile platform mass and
each wheel along the wheel axis direction is defined
as \( a \). The perpendicular distance from the center of
mobile platform mass to the wheel axis is \( b \). Con-
sidering only the mobile platform, the system can be
expressed by the following generalized coordinates
with five variables.

\[
\mathbf{q} = [x, y, \theta, \phi_h, \phi_l]^T
\]

where \( (x, y) \) is an absolute position of the center
of mass, \( \theta \) is an absolute rotation angle of the mobile
platform, and \( \phi_h \) and \( \phi_l \) are angular displacements
of the right and left wheels. Assuming that the mobile
platform is a nonholonomic system, there exist three
constraints caused by non-slip condition of the
wheels. The first constraint is that the lateral direc-
tion velocity of the wheels is confined to be zero (Eq.
(2)). The second and third constraints are originated
from an assumption that no slip happens during
forward or backward rolling motion of the wheels
(Eqs. (3) and (4)). These constraints can be formu-
lated as three equations explaining a wheel’s behav-
ior and a velocity relationship between the mobile
platform and wheels like follows.

\[
-\dot{x}_h \sin \theta + \dot{y}_h \cos \theta - \dot{\theta} = 0
\]

\[
\dot{x}_l \cos \theta + \dot{y}_l \sin \theta - a \dot{\theta} = r \phi_l
\]

\[
\dot{x}_l \cos \theta + \dot{y}_l \sin \theta - a \dot{\theta} = r \phi_h
\]

where \( r \) is a radius of the wheel.

As shown in Fig.1, the WMM is configured by a
combination of a serial manipulator with two links
and two revolute joints and a mobile platform. It is
assumed that the attached manipulator generates
only 2-dimensional planar motion. In Fig. 1, \( l_1 \) and \( l_2 \)
are lengths of link 1 and link 2, \( l_{11} \) and \( l_{12} \) are posi-
tions of center of mass of link 1 and link 2, and \( \phi_1 \)
and \( \phi_2 \) are absolute link angles with respect to the
global coordinate system \( \{XY\} \). The full set of ex-
tended generalized coordinates which add the serial
manipulator configuration variables to the mobile
platform configuration variables is represented by
following vector.

\[
\mathbf{q} = [x, y, \theta, \phi_h, \phi_l, \phi_1, \phi_2]^T
\]

Not only the position and velocity kinematic equa-
tions of the WMM but also the dynamic equation is
derived with above extended generalized coordi-
nates. Three nonholonomic constraints derived
above are rearranged like follows.

\[
C(q)\dot{q} = 0
\]
where
\[
C_{w,v} = \begin{bmatrix}
-\sin \theta & \cos \theta & -b & 0 & 0 & 0 \\
-\cos \theta & -\sin \theta & -a & r & 0 & 0 \\
-\cos \theta & -\sin \theta & a & 0 & r & 0
\end{bmatrix}
\]

\(\alpha(=3)\) is the number of constraints and \(\nu(=7)\) is the number of extended generalized coordinates. From above relationship, a proper null-space matrix \(T\) which satisfies \(CT = 0\) can be obtained. In the meanwhile, a velocity vector of the extended generalized coordinates is expressed as a vector with \(\nu(=u - v)\) independent velocities like follows.

\[
\dot{q}_{w,v} = T \cdot \dot{v}_{w,v+1}
\]

where
\[
a_{w,v} = [\dot{\phi}_w, \dot{\phi}_v, \dot{\phi}_1, \dot{\phi}_2]^T,
\]

\(e = r/2a\) and

\[
T_{w,v} = \begin{bmatrix}
    e(a \cos \theta - b \sin \theta) & e(a \cos \theta + b \sin \theta) & 0 & 0 \\
    e(a \sin \theta + b \cos \theta) & e(a \sin \theta - b \cos \theta) & 0 & 0 \\
    1 & 0 & 0 & 0 \\
    0 & 1 & 0 & 0 \\
    0 & 0 & 1 & 0 \\
    0 & 0 & 0 & 1
\end{bmatrix}
\]

With respect to the global coordinate system, assuming a planar coordinate of the end-effector is a task-space position \(Z\), a Jacobian matrix \(J\) which relates the joint velocity \(q\) of the WMM to the task-space velocity \(Z\) is defined by Eq.(9).

\[
\dot{Z}_{w,v} = J \dot{q}_{w,v}
\]

where
\[
J_{w,v} = \begin{bmatrix}
1 & 0 & -l \sin \theta & 0 & 0 & -l \sin \theta_1 & -l \sin \theta_2 \\
0 & 1 & l \cos \theta & 0 & 0 & l \cos \theta_1 & l \cos \theta_2
\end{bmatrix}
\]

\(s\) is the number of coordinates of the planar position of the end-effector. Substituting Eq.(7) to Eq.(9), a transformed Jacobian \(J'_{w,v}\) is obtained, which relates the task-space of the end-effector to the independent joint velocities by Eq.(10)

\[
\dot{Z}_{w,v} = J' \dot{w}_{w,v}
\]

**DYNAMIC MODELING OF WMM**

In order to derive a governing equation for dynamic analysis for the WMM, Lagrangian formulation is utilized. The WMM is composed of five distinct rigid bodies, mobile platform, right wheel, left wheel, manipulator link 1 and manipulator link 2. It is assumed that two wheels of the mobile platform and two revolute joints of the serial manipulator have ideal linear damping. These four elements are actuators to generate motion and their torques are produced by ideal torque-controlled motors. The end-effector attached to the end of the manipulator is connected to the external environment with a pin-joint. Therefore, the interaction between the end-effector and the environment doesn’t cause torque but force with x-y components. With the help of aforementioned conditions and Fig.2, the dynamic equation of motion of the WMM is derived like follows.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I_w)</td>
<td>Wheel inertia</td>
</tr>
<tr>
<td>(c_L, c_R)</td>
<td>Wheel damping</td>
</tr>
<tr>
<td>(m_w)</td>
<td>Wheel mass</td>
</tr>
<tr>
<td>(m_c)</td>
<td>Base mass</td>
</tr>
<tr>
<td>(I_c)</td>
<td>Base inertia</td>
</tr>
<tr>
<td>(I_1)</td>
<td>Link1 inertia</td>
</tr>
<tr>
<td>(I_2)</td>
<td>Link2 inertia</td>
</tr>
<tr>
<td>(m_1)</td>
<td>Link1 mass</td>
</tr>
<tr>
<td>(m_2)</td>
<td>Link2 mass</td>
</tr>
<tr>
<td>(d_1, d_2)</td>
<td>Joint damping at points (R_s) and (R_i)</td>
</tr>
<tr>
<td>(\tau_R, \tau_L)</td>
<td>Wheel input torque</td>
</tr>
<tr>
<td>(\tau_1, \tau_2)</td>
<td>Motor torque at points (R_s) and (R_i)</td>
</tr>
<tr>
<td>(F_x, F_y)</td>
<td>Environmental force at the end-effector</td>
</tr>
</tbody>
</table>
\[
M(q, \dot{q}) \ddot{q} + K(q, \dot{q}) \dot{q} = G_2 \dot{\lambda} - T
\]
\[
Cq = 0
\]

where \( M \) is a \( u \times v \) inertia matrix expressed by the extended generalized coordinates, \( K(q, \dot{q}) \) represents Coriolis, centrifugal and gravitational forces, \( \tau = [\tau_1 \tau_2 \tau_3 \tau_4]^T \) means actuator input torques that drive two wheels and two link joints and \( F = [F_x F_y]^T \) is an external force which is transferred to the end-effector. \( G_1 \) matrix maps the active input torques to joint-space and \( G_2 \) matrix maps the task-space end-effector force \( F \) to joint-space. \( \lambda \) is a Lagrangian multiplier. Dynamic parameters are given in Table 1 and detailed information of matrix \( M \), \( K \), \( G_1 \), and \( G_2 \) is like follows.

\[
M = \begin{bmatrix}
   h_1 & 0 & -h_2 \sin(\theta_1) & 0 & 0 & -h_3 \sin(\phi_1) & h_4 \sin(\phi_1) \\
   0 & h_5 & h_6 \cos(\theta_1) & 0 & 0 & h_7 \cos(\phi_1) & h_8 \cos(\phi_1) \\
   -h_2 \sin(\theta_1) & h_6 \cos(\theta_1) & h_9 & 0 & h_{10} & h_{11} & h_{12} \\
   0 & 0 & 0 & h_{13} & 0 & 0 & 0 \\
   0 & 0 & 0 & h_{14} & h_{15} & 0 & 0 \\
   -h_3 \sin(\phi_1) & h_7 \cos(\phi_1) & h_8 \cos(\phi_1) & h_9 & 0 & h_{10} & h_{11} \\
   -h_4 \sin(\phi_1) & h_8 \cos(\phi_1) & h_9 & h_{10} & h_{11} & h_{12} & h_{13}
\end{bmatrix}
\]

\[
K = \begin{bmatrix}
   K_{11} & K_{12} & K_{13} & c_{\phi_1} \dot{\phi}_1 & c_{\phi_1} \dot{\phi}_2 & K_{15} & K_{16}
\end{bmatrix}
\]

\[
G_1 = \begin{bmatrix}
   1 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}^T
\]

\[
G_2 = \begin{bmatrix}
   1 & 0 & 0 & 0 & 0 & 0 & 0
   0 & 0 & 0 & 0 & 0 & 0 & 0
   -l_1 \sin(\phi_1) & l_1 \cos(\phi_1) & -l_1 \sin(\phi_1) & l_1 \cos(\phi_1)
\end{bmatrix}
\]

\[
(11)
\]

\[
(12)
\]

\[
(13)
\]

\[
(14)
\]

\[
(15)
\]

CONCLUDING REMARKS

In this research, kinematic and dynamic modeling of the WMM was performed which is a preliminary work for redundancy resolution. Generalized coordinates were defined on joint-space and a position kinematic equation was derived, which relates the joint variables of the robotic system to task-space variables for an end-effector position. Based on these derivations, a Jacobian that is a velocity relationship of the two spaces was obtained. Finally a dynamic equation of motion was derived, which is a correlation between an external force to the end-effector in terms of task-space and an internal torque of the robot joints in terms of joint-space. Above governing equations were calculated based on three non-slip constraints that are given under an assumption that the WMM is a nonholonomic system. For further research, detailed optimal selection issues with various redundancy resolution methodologies will be performed using kinematic and dynamic equations obtained by this paper. In addition, to derive some governing equations for omni-directional mobile manipulator (OMM), which is another alternative to replace the nonholonomic WMM with, will be studied.

ACKNOWLEDGEMENT

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References


A new generation of collaborative robots for material handling

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Purpose The handling of material is a high resource consuming task in many different manufacturing industries and especially in the construction sector. Global demand for material-handling products is projected to rise by 7.0 percent annually until 2014 to a total of $119 billion. Typically, work on the construction site, in the materials distribution process or in the construction materials production, includes extensive material handling tasks. Advanced automation and robotics technologies can enhance the productivity of this process, guaranteeing at the same time the highest level of safety for workers. Modular reconfigurable robotic systems are considered as one of the most challenging topics. A worldwide cutting-edge technical solution for material handling, based on the development of a modular intelligent power assists systems (collaborative robots, COBOTS), is presented in this paper. Method Conventional manually-guided handling systems lack an intuitive and responsive control and may lead to back discomfort and fatigue. A significant improvement has been achieved by power-assisted systems developed by Stanley Cobotics in the USA, as well by the first cobot prototypes in German industry implemented through cooperation of IPK and Schmidt-Handling GmbH. The proposed material handling approach would constitute a significant breakthrough by bridging the gap between fully automatic and manual technologies. The developed intelligent power systems are capable of working with people also in a direct physical contact, combining human flexibility, intelligence, and skills with the advantage of sophisticated technical systems. Safety issues have been considered to be of paramount importance. Results & Discussion A modular flexible collaborative robot prototype has been designed and developed as a demonstration of the proposed new generation of material handling methodology. This technology supposes a break with traditional paradigms regarding flexibility, cost, accessibility and applicability of high-tech handling solutions as well as conventional human-machine interaction. The control system is based on hierarchical order control block architecture. Since a collaborative robot is characterized by real cooperation between human workers and intelligent assist devices, an elaborate safety system has been developed. The prototype can operate in an area of about 4.7x2.4m including travel in Z-direction of about 1.3m. It has five powered axes driven by servo drives. The axes are the X-, Y- and Z-axes, rotation about the Z-axis and pivoting up and down of the end effector. To allow simple and friendly interfacing with the human worker, a sophisticated human machine interface, based on a touch panel, has been developed.

Keywords: material handling, collaborative robots, modular robots, robots in construction.

INTRODUCTION

In the manufacturing industries, and especially in the construction industry, a lot of efforts are expended in material handling tasks. This situation has produced a significant increase in the demand of material handling products that allows reducing these efforts, decreasing the consumed time and the costs of this activity. Global demand for material handling products is projected to rise 7.0 percent per year till 2014 to $119 billion1. Materials handling products and systems are found in almost every manufacturing and distribution company and for an endless number of goods. If we put our focus in the construction industry, material handling tasks are present in typical works in the construction site, in the materials distribution process, or in the construction materials production.

During many years, material-handling products has been developed using traditional manipulating technologies, trying to reduce the worker efforts in lifting and moving materials. However, conventional manually guided handling systems are in lack of intuitive and responsive control that may cause back discomfort and fatigue. Current industry trends, such as shorter product lifecycles, reduced time-to-market and mass-customization require new paradigms and approaches for handling technology. The growing numbers of product variants and dimensions, as well as smaller lot sizes, have led to increasing demands on flexible material handling equipment and concepts. They must realize high flexibility related to variants, cost-effective adaptability to specific products and processes, and quick in-process reconfiguration and set-ups. In order to master these challenges, innovative approaches and technologies are required. Automation and robotics technologies have
been applied in order to contribute to solve these problems. To tackle the problems on reconfigurability and agility the semi-automatic approach is the best solution, combining flexible automation and human skills. For the manual material handling, various assist devices are available on the market. However, for applications requiring rapid and accurate movements, they are slow, awkward, non-responsive and difficult to be manipulated. A significant improvement has been achieved by power-assist systems developed by Stanley Cobotics in the USA\(^2\), as well as by the first cobot prototypes in Germany industry, implemented through cooperation of Fraunhofer Institute for Production Systems and Design Technology (IPK) and Schmidt-Handling GmbH\(^3\).

In order to reduce the costs and increase the usability, modular reconfigurable robotic systems are considered as one of the most challenging topics to solve material handling problem\(^4\). A completely new technical solution for material handling, based on the development of a modular intelligent power assists systems (collaborative robots – COBOTS), is presented in this paper. The proposed material handling approach supposes a significant break-through that bridges the gap between full automatic and manual technologies\(^5\). The developed intelligent power systems are capable of working with human also in a direct physical contact, allowing to combine human flexibility, intelligence and skills with the advantage of sophisticated technical systems. Safety issues have been considered of paramount importance.

A modular flexible collaborative robot prototype (COBOT) has been designed and developed as a demonstration of the proposed new generation of material handling methodology. This technology supposes a break with traditional paradigms regarding flexibility, cost, accessibility and applicability of high-tech handling solutions as well as conventional human-machine interaction. The COBOT prototype has been tested performing the assembly of windscreens in a car assembly line, a typical task in the automotive industry. This demonstration task presents many similarities with typical construction tasks, where it is necessary to move and assembly construction materials.

**COLLABORATIVE ROBOT MECHANICAL SYSTEM**

The COBOT demonstration system in (Fig. 1) has been developed to meet demands on flexible and advanced integration of the novel cobotic technology in automotive industry assembly lines. This use case allows to demonstrate their capabilities of material handling and precision assembly operations. The demonstrator has been developed as a 5-DOF gantry robot (Fig. 2) with 3 translational and 2 rotational (TTTRR structure) servo controlled axes. An additional passive mechanical rotational axis around the screen vertical axis has been realized. The prototype can operate within an area of about 4.7 m x 2.4 m including a travel in Z-direction of about 1.3 m. It has five powered axes driven by servo drives. The axes are the X-, Y- and Z-axes, rotation about the Z-axis and pivoting up and down of the end effector. The maximum acceleration in X, Y, Z is 1 m/s\(^2\), and the maximum speed in X, Y, Z is 30 m/min.

![Fig.1. COBOT demonstrator layout](image)

The end effector (Fig. 3) consists of a gripper with four spring loaded vacuum cups. It is designed to handle the front windscreens and the rear window of a passenger car that weighs about 20 kg each. The vacuum gripper is designed to pick up the front and the rear window with one set up via suction cups. The spring loading mechanism is mandatory to make up for the different curvatures of the two window types. It also supports the mounting process and allows the Cobot to be less precise. There is an ultrasonic sensor that detects the available window on the rack and thus enables the switching on of the vacuum. The pivot point allows the gripper to rotate a few degrees around a detent, in order to allow a slight manual adjustment of the window during the assembly process and also to take stiffness out of the system.

![Fig.2. Kinematics of the COBOT](image)
Different from conventional industrial gantry robots, the cobot demonstrator has a relatively lightweight low-cost mechanical structure which absolute precision does not play an essential role by task accomplishment. The critical assembly operations are performed in cooperation with human. Thereby the human operators are responsible to manually guide the cobot to position the windshield in the car-body frames.

The gantry cobot has been designed over a virtual assembly line fixed to the ground. The car bodies (mock-ups) are moving along the virtual assembly lines. The demonstrator includes also a virtual glue station where the cobot should automatically pick-up the screen (using vacuum suction cups) and positions it close to the car-body. Thereby the cobot follows the car-body motion on the line. The system keeps a prescribed distance to the car body until the operators grasp the handling devices (i.e. both hand gripper with sensors) and activate the manual guided assembly phase. After human guided screen assembly the vacuum grippers are released (using switches in the grippers) and the cobot automatically start the retract operation (from the body car). After reaching a start position, the entire cycle is repeated.

For safety reasons the travel speed is limited to 0.25 m/s in interactive (manual) mode and 0.5 m/s in automatic mode. The prototype includes moving indicator lamps and emergency stop buttons.

**MECHANICAL AND ELECTRICAL INTERFACES**

The mechanical interfaces are the flange for different end effectors and the steel frame. As for the Cobot the flange consists of a simple plate with four tapped holes. This plate is integrated in the housing of the load cell. The steel frame rests on four stands (see picture 5-2) and has a size of 4.5 m x 6 m x 4 m (width x length x height). The steel frame is a free-standing structure, but the feet of the frame could also be screwed to the floor.

The electrical interfaces are:
- Plug for 400 V three-phase current to be turned on and of with a respective switch, mounted on one stand of the steel frame.
- Emergency Stop switch close to operator handle bar
- Additional emergency stop switch(es) at locations to be determined
- Ethernet network connection to attach PC for service of Cobot control

The prototype also includes a pneumatic 6 bar dry air supply for the end effector operation. Figure 4 shows the COBOT prototype working in manual mode.

**CONTROL SYSTEM ARCHITECTURE**

The cobot control system (CCS) represents a central part of the Cobot prototype (Fig. 5) that integrates all system modules: the cobot mechanical part with digital drives (communication has been realized by EtherCAT), safety controller, assembly planning and programming environment and human-machine interface. The cobot controller provides a sophisticated PC based control system (running under Windows CE and integrated in the Beckhoff TwinCAT real-time environment) providing high level (at action-layer) robot/cobot programming and sensor-based control functions (compliance control, haptic rendering etc.). An assembly task-programming
The environment supports the task-oriented programming of robot/cobot applications involving off-line simulation tests of programs and system performance. A human-machine interface supports the specific role of the human-operator during commissioning of the system in a work place, including: environment calibration, “manual” i.e. “walk-through” programming (teaching).

Considering a cage less dual-cobot application (the human is in operational, i.e. achievable workspace,) specific attention in the prototype development is focused on the human and system safety. A special safety controller monitors all system components and human-operator caring for human and environment safety. The safety is not provided as an add-on by the safety controller, rather is an intrinsic part of each module that includes internal safety monitoring and exception handling functions. The safety controller provides additional system safety functions enabling the human operator to come into the robot-workspace in order to realize a task (e.g. interactive windscreen fine-positioning and final assembly). This system integrates additional safeguarding sensors (e.g. laser scanners) and via direct interfaces with the robot controller has the possibility to slow done, hold, stop robot motion or to start a reflective safety action (e.g. stop current motion and starting moving the robot in a contrary direction or to home position).

The prototype CCS system has been developed to meet the following SP1 objectives:

- Integration of intelligent control algorithms supporting semi-automatic and interactive human-robot collaboration, also including direct physical interaction.
- Efficient intuitive programming, including task-oriented, lead-through (“walk-through”) teaching programming based on manual-guidance.
- Easy integration in complex assembly demonstration applications in industry (e.g. wind-screens assembly).
- To ensure human and environment safety and protection based on recent robotics and other safety standards and norms

The Cobot functional system architecture, based on a standard hierarchical robot control (ESA Functional reference model – FRM), is presented in figure 6. The main idea of this model is to decompose a complex activity at lower layer components that can be executed by various algorithms and assigned to specific subsystems. This model provides a hierarchical multi-layer control framework. The COBOT functional architecture assumes 4 horizontal layers assembly process control (planning and execution), Task-layer control, Action-layer control, and Servo-layer control. The vertical hierarchy includes the following layers: Forward Control functions – FC involving nominal control functions, Nominal feedback – NNF – caring for external sensor data processing and feedback control loops, and Non-nominal feedback – NNF – performing monitoring function, error detections and exception handling. The safety functions are divided into basic safety function, handling the COBOT device safety issues, and system safety control managing the safety of the entire cobot assembly system.

**ROBOT PROGRAMMING**

The programming of the Cobot prototype is based on a high-layer action-oriented programming approach. An action represents lowest level of activity that can be assigned to specific device (e.g. robot/cobot arm, gripper, etc.) and realized based on an appropriate control algorithm. The basic single-arm actions can be split into: non-contact (free-space motion) and contact actions. The specifics actions can be further implemented in the developed programming environment. The basis for the actions programming and
environment modeling provides a set of coordinate systems (world-model) and predefined relative poses to these frames.

The assembly tasks represent higher-level activities composed of elemental actions. The goal of task programming is to decompose tasks into elemental actions.

The control architecture of the cobot arm includes common hierarchically ordered control blocks: for the execution of action programs, planning of elemental motion, real time computation of Cartesian set-points, inverse kinematics and servo-local joint control including dynamic feed-forward (compensation of nominal dynamics). A specific key functionality for the controlling human-cobot-environment interaction is position-based compliance, i.e. impedance control. The compliance control allows controlling the physical interaction between the arms and environment, as well as the arms with each other, while maintaining the interaction forces within prescribed limits despite tolerances and inaccuracies. Practically, impedance control provides a basic control approach for all contact (essential and potential) operations. The compliance control will also be used in so-called damping mode for the manual guidance and programming of the robot. By a proper robust synthesis of damping gains sets for the manual guidance in free-space and for the stable transition to the contact, respectively, a good system performance (e.g. fast responsive reaction in the free-space and stable contact transition and guidance in the constraint space) may be achieved.

A special COBOT control functionality represents haptic rendering of virtual walls and controlling the interaction with stiff or flexible virtual obstacles. These functions also utilizes robust robot-environment stable interaction framework. The virtual walls are useful not only to restrict some working area and prevent damages, i.e. injuries, but also to support guidance (e.g. along a virtual wall or cone) to the goal pose.

EXTERNAL SENSORS
The relevant external sensors integrated in the Cobot system are force-torque sensors supporting the control human-robot-environment interaction. Two force-torque sensors are implemented: a 6 DOF compliant sensor for human-robot interaction (manual guiding) integrated in the hand-grasping interface and a 1 DOF contact sensor for the contact detection and monitoring. Figure 7 shows the 6 DOF force-torque sensor in the robot wrist.

Force-torque sensors are essential for the implementation of the above described compliance control method and damping mode that allows manual guidance tanks and direct programming of the robot.

Assembly and precision tasks can be accomplished by means of the contact detection provided by the external sensors.

Fig.7. Compliant F/T sensor for human-robot interaction

HUMAN-MACHINE INTERFACE
The main human machine interface has been implemented using a touch panel CP (Fig. 8).

The touch panel PC provides a graphical user interface (GUI) that allows to start the Cobot, to program it, to switch between different modes and to provide user interfaces for different operators who have more or less limited access to the Cobot control.

Fig.8. COBOT Graphical User Interface

The touch panel PC also provides feedback to the operator and inform about modes, failures, and states of the Cobot.

In addition there are signal lights on various locations of the Cobot and especially its control box. One light, a flashing light at the control box, signalizes that the Cobot is moving in autonomous mode. Another light signalizes the three different modes: autonomous mode (yellow), manual mode (green), or failure (red).

EVALUATION OF USABILITY
The usability tests were performed using several experienced and non-experienced users. In addition the experience with the numerous users at MOTEK
2009 fair was utilized. The main test was to perform manual guidance using different target behaviors (with and without stiffness) and to perform test tasks consisting of manual guidance, positioning, grasping and finally cooperative assembly of wind screens (using plastic mock-ups).

The test results for the manual guidance and positioning were very good in almost all cases which represents an additional significant improvement in comparison to the state of the art systems and development at the project start. However, the assembly of the screen requires some training and coordination between both operators. In almost 50% of the tests one or both users expressed some difficulties and expressed needs for additional training.

The operability using GUI, handle interfaces or external cobot GUI on a PC was in all cases evaluated as very intuitive and simple. As a critical issue, the position of the user interfaces (handles and mounted GUI) in some cobot poses (e.g. extremely low or high position in z directions, or at maximum horizontal rotation axis stroke) were estimated as not ergonomic. Also the process monitoring by a single-man operation with both hands was evaluated as not enough (due to occlusion by cobot structure) and should be improved in the future products.

**Collaborative Robots vs Automatic Systems**

Usually completely manual guided robotic systems cannot adequately deal with complex manipulating and/or assembly tasks. Completely automatic robots could be able to perform these tasks with good results, but in many cases with a very high cost. However, collaborative robots present several advantages. In these systems accuracy, flexibility and intelligence is obtained by the combination of the control strategy, technical systems and the presence of the skills of the human operator, instead of using expensive full automatic technologies. Real experiments have shown the benefits of this strategy in the assembly of wind screens in a car assembly line comparing with traditional full automatic solutions.

**Conclusions**

Collaborative robots, which combines the benefices of human intelligence and skills with the advantage of sophisticated robotic technical systems, have been demonstrated their advantages when using in material handling tasks. In order to improve their reconfigurability and flexibility the modular approach is the best solution. A completely new modular collaborative robotic concept has been presented in this paper, showing the benefits of using a real prototype in a typical use case for the automotive industry. This methodology can be translated to other manufacturing industries and especially to the construction industry, where material handling and assembly requires considerable efforts.

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**References**

A novel MiniOn Agent Assisted Robotic Kitchen Platform

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Purpose Elderly people tend to have several light, or even severe, disabilities, constraining them from most of every household task. Additionally, they tend to consume much of their daily time in the kitchen environment. A typical kitchen arrangement might be useful to most of us, but the actual arrangement and functionality is of greater importance when it comes to ageing society. The proposed paper deals with a novel robotic kitchen environment specifically designed to assist elderly individuals.

Method Demographic change design deals with providing design solutions and services oriented on specific population categories. The ageing society receives a non-negligible concern in this area, since this population category requires a quite different design approach in household environment. A compact and modular approach design is proposed, providing enhanced functionality, information technology services, and the ability to accommodate MiniOn individual robotic agents, to support the individuals while cooking, serving or cleaning up. Various kitchen design models were studied in order to conclude the design of the proposed prototype. Test cases were conducted in a real kitchen environment to acquire enough knowledge and to depict the actual problems and limitations the ageing society faces, while performing these relevant tasks.

Results & Discussion The proposed kitchen system comprises a series of robotic actuators and sensors, novel space utilization techniques, and a set of visually guided robotic agents to assist in most of the required kitchen tasks. The performance of such a kitchen environment system, can undoubtedly embrace future design approaches, and strongly contribute in demographic change design.

Keywords: Ambient Integrated Robotics, kitchen design, mobile robots

INTRODUCTION Domestic architecture constantly undergoes changes and transitions. In ancient times it began with an open fireplace. The fireplace was later integrated in the building. That introduced some risky conditions in the home environment considering CO₂ air concentration. The situation hadn’t been changed much until the beginning of industrialization, when the first iron stoves, which enclosed the fire completely, were produced. However, the design of the kitchen wasn’t influenced by the cooking process. This changed with the Frankfurt Kitchen designed by Margarete Schütte-Lihotzky. She was mainly affected by the ideas of Fredrick Winslow Taylor. Taylor analyzed and synthesized workflows. The Frankfurt kitchen is a designed concept for optimized, fitted kitchen, influenced by the workflows of its time. The proposed study deals with a new interpretation of the Frankfurt Kitchen. Nowadays, it is necessary to focus more and more on human needs and health care, since the possibilities change due to the recurrent advances in technology. For example household daily activities can be performed by robots and it is possible to develop furniture with sensors for measuring the vital functions (Figure 1). Initially a survey on various existing technologies was performed. Activities of Daily Living and the Frankfurt Kitchen were concerned. After that, the paper describes the experiments conducted in order to define the proposed implementation specifications. The resulting findings defined the concept and solution approaches.

RESEARCH AND SURVEY Since spending time in the kitchen is one of the main parts of our daily routine, the research began by collecting information about basics of the modern kitchen. This included the Frankfurt kitchen and the workflow analyses. As an important basis, daily activities and the Frankfurt kitchen will be explained in detail in this section. New ideas and state-of-the-art
inventions in this area were collected. The collected information was analyzed into 2 main focus areas: 1) transformation in space and architecture as well as 2) optimization by multi-functionality. For example traditional Japanese-rooms show the transformation process in space, Figure 2. By utilizing sliding doors, the atmosphere and usage of the room can be easily altered. Their specially designed floors which are made from Tatami mats, a special flooring material, provide the opportunity to use the room for different activities, for example as lounge at day-time and as bedroom at night time.

Fig.2. Traditional Japanese-room with sliding doors and Tatami mat floors

To increase the multi-functionality of a device or a system, the appropriate workspaces have to be defined, Figure 3. Also the personalization is important to increase the wellbeing of the user. A system that can in some extend be adapted to the personal needs or requirements of a user, provides extended functionality, while at the same time increases its efficiency to a higher degree.

Fig.3. Definition of workspaces, motion analysis

Activities of Daily Living

The term "Activities of Daily Living," or ADLs, refers to the basic tasks of everyday living, such as eating, bathing, dressing, toileting, and transferring. When people are unable to perform these activities, they need assistance in order to cope, either from other human beings or mechanical devices or both. Although persons of all ages may have problems performing the ADLs, prevalence rates are much higher for the elderly than for the nonelderly. Within the elderly population, ADL prevalence rates rise steeply with advancing age and are especially high for persons aged 85 and over.

A number of national surveys which measure the ability of elderly people to perform the ADLs have been conducted. Even though all ADLs have a different rate of occurrence, elderly people tend to spent most of their everyday time in the kitchen, in order to prepare their meals or take their medication. The need for feeding themselves becomes dominant, and comprises one of their most important activities in their everyday living. Most elderly people have to prepare their meal more than 4 times a day, which can be considered a pretty time demanding and difficult to accomplish task, in an everyday situation scenario. Additionally, the risk for accidents in the kitchen environment is greater, since the lack of instant reflexes and the presence of fatigue, greatly raises the chances of harming themselves, many times even with tragic consequences.

The proposed Robotic kitchen introduces a novel approach, efficiently dealing with the ADLs considering the ageing society. The main idea is to introduce a kitchen design that can simplify the work process in order to prepare a meal, adapt to the elderly people profile, improve the quality of their living, and reduce the accident risk to a minimum level by implementing an intelligent and safe kitchen environment.

Frankfurter Kitchen

The Frankfurt Kitchen had a long lasting effect on the design of the modern kitchen. Although it wasn’t Margarete Schütte-Lihotzky, who analyzed workflows, she was the one who structured the ideas of managing the cooking processes and realized them with the Frankfurt Kitchen. Originally Fredrick Winslow Tailor analyzed and synthesized workflows and this theory of managing the working process is also called Taylorism. Margarete Schütte-Lihotzky was an Austrian architect and her aim was to simplify the daily routine of a housewife and save time by rearranging furniture at the right order. The kitchen was also designed only for one person and included no maid, which was very unusual at that time. Schütte-Lihotzky defined Workspaces and invented space-saving storage elements. Due to mass production she was also able to produce the kitchen with rela-
tively low cost. The Frankfurter Kitchen arrangement is depicted in Figure 4.

**EXPERIMENTS**

The study included experiments in a real kitchen environment to acquire enough knowledge and to depict the actual problems and limitations the ageing society faces, while performing relevant tasks. Those experiments analyze the cooking process, the cognitive support and the required space for every cooking step.

**Cooking Process**

The first experiment aimed to analyze the motion paths performed during cooking, define difficulties and obtain impressions. The experiment subject used a standard kitchen and simulated the usage during preparing an average meal.

**Cognitive Support**

The second experiment dealt with examining the cognitive support, which becomes more and more important in ageing society. The vast majority of elderly people lack the ability of sharp vision. It is thus very difficult for them to easily identify household items location even if they are stacked in a cabinet. A standard kitchen was accordingly modified to test cognitive support and distraction factors were defined.

**Space Requirement**

Finally the required space for every cooking step was examined and stated. Therefore kitchen utensils were assessed on size, number and frequency of use. The use of these utensils was simulated, for example to cut vegetables or to cook with a pan.

**RESULTS**

This cooking process experiment revealed that the test person multitasked and organized different steps in a parallel scheme. For example during water boiling, the test person prepared vegetables for braising...
pot roasting). Important are also significant steps, like cooling off of the stove cookplate. Likewise it is interesting that the test person movements like to bend down to the oven, or stay stood, comprise a challenge for ageing society groups. Disabilities or body stiffness and pain due to old age require a completely different approach than healthy individuals.

To simplify the working process it is important not only to optimize every work step but also to correlate them. Cognitive support aids in this correlation procedure. For example if tags or pictures are placed on the cabinet doors, the person doesn’t need to remember were the kitchen utensil are located or redundantly spend time to acquire one, optimizing thus the cooking process.

Minimization of the required space is necessary, because elderly people require increased free space for themselves, in order to move easily and without struggle. The experiment showed that table modules with a minimum size of 35cm x 35 cm, provide the adequate area for implementing the cooking procedure, and at the same time allow sufficient free space for movement. These table modules are combined to increase the efficiency and adapt to the given situation.

CONCEPT
The obtained results induced a concept with a modular system as basis. The challenge was to find the right combination between flexibility and efficiency. The modules were designed into three different variations to handle as well the demanded installations: fixed, semi-fixed, and flexible, Figure 8. Additionally they were designed to enable efficient work and to be adaptable for each user and working process. So every user can apply its own workspace, Figure 9.

SOLUTION APPROACH
The proposed system solution approach followed the concept realization and definition of the system modules. The idea behind the fixed installation modules is to combine them with the storage part and kitchenware. The flexible modules can also comprise autonomous mobile robots with integrated functions. It seems to be useful to separate the fixed modules into two kinds of modules. One is the main module of the kitchen, which integrates important kitchenware as well as storage for the most frequently used utensils. The second fixed module focuses mainly on storage, but offering the ability to vertically elevate the required compartment to eye-level, in order to assist in easily retrieving an item, without needing to reach high or bend down, which is an activity that introduces struggle to the ageing society. Elderly people tend to use items stored in their kitchen cabinets that are in eye-level, while disregarding all other that are placed in positions that are hard to reach.

Considering the first fixed module configuration, Figure 10, a storage module was designed, where the most frequently used kitchen utensils are stored. Additionally, 3-axis integrated robotic arm acquires objects with an electrostatic gripper and distributes...
them in the storage cases. A compact size dishwasher can save energy by detection of quantity and dirt level. The work space has an opening for waste. The Waste bin is placed under the opening. The option to sort is also possible. For ease of use the oven has a retractable platform. The dishes will be positioned in place, and then the platform is inserted into the oven by the use of a set of controlled servomechanisms.

The fixed module depicted in Figure 10, also houses a touch screen display interfaced to a mini-PC located at the bottom part of the module. The mini-PC is also interfaced via WiFi wireless technology to a vital sign measuring getaway located in the same position. By using a set of tele-monitoring devices (a blood-pressure meter, a blood-glucose level meter, and a scale measuring the BMI index), the user can wirelessly monitor own health status, and present readings on the touch screen display. This offers a user friendly vital sign measuring terminal, which functions as a database to store vital sign readings and at the same time enabling access to them over a remote location by a specialist. Connection to the World Wide Web, allows for ICT services, such as tele-care and tele-medicine, remote health assistance, remote health consultancy. Elderly people due to severe or light disabilities and health problems, usually isolate themselves within their home environment. A visit to the doctor for a regular check up might be impossible by some individuals facing such difficulties. Interfacing a health care terminal with the proposed robotic kitchen platform is undoubtedly contributing to an enhanced service delivery scheme.

The MiniOn robotic agents consist of a square plate with a length of 35cm x 35cm attached to a telescopic base. The telescopic base comprises a visually guided robotic platform2 which provides the necessary movement and environment perception abilities to the robotic agents. The user can adapt the telescopic base to the individual needs, so that this flexible module assists in cooking, serving and cleaning up.

The operation of the MiniOn mobile robots is based on an onboard optical sensor11, which has the ability to extract depth information of the acquired optical scene. Depth extraction efficiently deals with problems such as 3D reconstruction, positioning, navigation, obstacle avoidance, etc12, 13. The depth sensor consists of an infrared laser projector combined with a CMOS sensor, which captures video data in 3D. Once the MiniOn mobile robots are introduced into their working space, the exact space arrangement must be known, in order to enable autonomous operation. A widely known technique which provides this kind of information to autonomous vehicles is the Simultaneous Localization and Mapping (SLAM)14. SLAM is a technique used by robots and autonomous vehicles to build up a map within an unknown environment (without a priori knowledge), or to update a map within a known environment (with a priori knowledge from a given map), while at the same time keeping track of their current location. Such a technique is used in the proposed MiniOn mobile robots, in order to get all necessary details concerning their operating area. Once the map of their environment is composed, the mobile robots can efficiently navigate within its space.

Each MiniOn can autonomously navigate in order to dock itself to different types of walls, or furniture. This is performed using label stickers, attached to the designated locations. The mobile robots scan the surrounding area using images acquired by their onboard optical sensor, and once the appropriate sticker pattern is detected within the optical scene, they are visually guided towards their target. A similar approach is used in order to be linked against each other to form the desired configurations. These modules are equipped with built-in functions, such as cooktops, scales, cutting boards etc. The different configurations of the mobile robots enable a variety of application possibilities to the user, Figure 11. The individual modules can be replaced or upgraded.
Thus, in this context a self-configuring robotic swarm system introduces a potential towards self-organizing environments, which can counter any unforeseen obstacles over a period of time and yet efficiently serve their intended purposes. The concept of self-configuration is a natural phenomenon and it can be observed even in the level of human biological structure. A lot of activities inside human body are carried out intelligently without the explicit intervention of human itself, e.g. various actions of nervous systems, blood circulation system, etc. Self configuration can be observed even in the microscopic level of cells in the human body. When a new cell is generated or if an existing cell dies within the human body the remaining body automatically self configures itself and adapts to the changes in the system. The advantage of self-configuring systems is widely used in the field of robotics to design robots which operate all possible scenarios and different terrains. To achieve this, the robot is broken down into modules or also called atoms and each module is self sustaining and has all necessary components inbuilt to sustain or perform on its own. So when faced with an obstacle these robots could transform themselves by changing configuration, shape and orientation and the individual modules adapt to the context at specific point of time.

The second proposed fixed module deals with storage, divided into three sections, Figure 12. The middle part consists of two fixed shelves in the back and a free space in the front. The free space can be used as work space, but is also required to place the upper and lower shelves at eye-level. The positioning of the shelves is performed using a set of electric motors. A "Rack and Pinion" type gearing mechanism is used to allow the various modules to move along the vertical axis. This principle enables three varieties to occupy the front middle part of the module.

The "Storage Module" simple serves us food storage compartment. The "Electric Module", is used to interface small electrical appliances, by providing connectors to the electrical grid power supply. Last, the "Cooling Module" houses refrigerator and freezer compartments.

**CONCLUSIONS**

A novel solution dealing with ADLs in the kitchen environment is proposed. The proposed system followed a research and development approach, in order to identify the strengths and weaknesses of the work processes in the kitchen environment. A series of experiments and studies were conducted concerning demographic change. The system was designed according to the needs and requirements of elderly people, since the overall goal was to realize a product assisting in ADLs in the kitchen environment, focusing in the ageing society. The results of the experiments conducted were appropriately evaluated, to adapt the functionality and operation accordingly.

The realized concepts and functions establish an approach, which allows further research and development towards robotic assisted kitchen environments. The ability to log and remotely manage the health status measurements of the user via a touch screen display integrated in the proposed system, offers a direct connection and communication between isolated elderly people and specialists, in order to conduct tele-consulting and tele-care, without requiring the individual to visit an appropriate healthcare facility quite often. Additionally, the use of MiniOn robotic mobile agents, allows reconfiguration according to the user needs, and adaptation to the current required conditions. A dynamic environment is thus proposed, offering customization and reconfigurability, modularity, while maintaining space saving efficiency.

**References**


Purpose Ergonomics is the engineering science that is concerned with the physical and psychological relationship between machines and the people who use them. The key is to get the best out of something with the smallest possible effort. In ergonomics function is as important as aesthetics. Ergonomics is concerned with the creation of a product or an environment, where the connection between human skills and the surroundings is optimized. The aim of the proposed paper is the implementation of an ergonomic furniture system concentrating on height adjustments in particular. Method Furniture is designed to adapt to specific needs, supporting various human activities. According to the application, a set of guidelines or rules is followed during design in order to provide ergonomic features. Small or large sized furniture can be found within the household, comprising individual modules, placed at a specific height, based upon the desired functionality. In order to realize the proposed concept, a development approach was followed. First, thorough research was conducted to identify the actual need of such a system and define the appropriate design specifications. According to the various existing technologies and processes, the authors identified those that met the design requirements, and those better adapted to the proposed system. Once the initial concept was finalized, a series of experiments were carried out in a real environment, implementing the prototype of the proposed system. Results & Discussion The proposed robotic furniture system provides an integrated solution, consisting of reduced space utilization, modularity, and intelligent operation, while respecting ergonomic principles. A set of electrical motors was used to position the various sections of the system at the correct height level, and to displace them on the horizontal axis to allow a rotational motion path. The implemented prototype was evaluated in terms of ergonomics (using an age simulation suite), organizational ergonomics within a room, and space utilization (as the individual sections/shelves can rotate in a vertical direction, the proposed system can be installed in small rooms, achieving 20% space utilization efficiency providing more space for mobility with walking frames or wheelchairs). A vision system was integrated into the prototype to perform object recognition—for efficient classification of objects stored into the various system sections, for assistance in retrieving a specific previously stored object by moving the appropriate section of the furniture up or down to the correct height. The real-time response of the vision system, efficiently addresses the need for a short time delay between user queries and system response. The robotic furniture system also serves as a lift, a seat, or a working place for elderly people, i.e. it efficiently applies ergonomics to issues in the living environment of the ageing society. Fusing functions and services such as infotainment or internet connectivity, also provides extended functionality to the user. Many everyday activities can be dealt with a more efficiently from a single terminal.

Keywords: ambient integrated robotics, ergonomic furniture, vision system, architecture

INTRODUCTION
A close look at the fixed and loose components of our environments shows that all components of the housing environment are gradually integrated with electronics and micro-systems. “Miniaturization” and “Downscale” as basic trends of our technological development today enable a seamless integration of sensors, actuators, control components and micro-electronic systems into all subsystems, components and appliances, in a persuasive but somehow invisible way. Today, robots and distributed robotic sub-systems start to permeate our every day surrounding, enhancing it with services and additional features. At the same time, this permeation is on the way to transform our perception of what robots are, robot technology, robots’ possibilities and the environment they are merged with. This transformation which has to be understood as a natural part of the evolution of robotics, will especially become visible when robots enter the field of service and assistance. Ageing society faces numerous challenges in performing simple tasks in Activities of Daily Living (ADLs). ADLs represent the everyday tasks people usually need to be able to independently accomplish. An environment populated with robotic elements and micro-systems can undoubtedly contribute in enhancing their independence, by introducing a degree of ambient assistance. It must be noted though that populating a home environment with robotic elements must be performed following a space-efficient utilization scheme. Elderly people, and especially the ones using assistive devices such as wheelchairs and rollators, require increased barrier-free space for mobility purposes. Therefore, the following article describes the design and implementation of a novel
robotic furniture system which also serves as a lift or seat, storage space, health assistance terminal, and working place for elderly people. Additionally, an integrated vision system implements the human-machine interaction assisting in detecting stored items in the robotic furniture, and aiding in efficiently retrieving them upon user queries issued by vocal commands. Thus, a compact terminal assisting the ageing society in ADLs by enhancing their independence, as well as offering extended ergonomy is proposed.

RESEARCH AND SURVEY
Some researchers already proposed integrated solutions as e.g. Robotic Rooms⁴, Wabot House⁵, or Robot Town⁶. The aim of those approaches was to distribute sensors and actuators in the environment which can communicate with the intended robot system, allowing simpler and robust robot designs. The main objective of these approaches was to assist humans in daily living by distributing mechatronic devices within environments to allow a human-machine interaction providing a series of services and applications. However, these approaches integrate mainly sensors, actuators and robots on an informational level. Furthermore, they are presenting implementations that are realized in a controlled experimental environment, and cannot be straightforwardly applied into a regular medium sized apartment. The proposed system focuses on providing a compact ergonomic system that can be easily installed within a home environment, without requiring major rearrangement procedures and modifications.

The required m² space ratio per person is rising continuously. Nowadays, according to national surveys, an average person requires approximately 45 m². Since the 1990s this figure has raised nearly by 10 m². Currently it rises about 0.55 m² per year. It is estimated that by 2030, 55 m² will be required per person. At the same time real estate prices in major cities around the world are skyrocketing. Thus, space utilization is becoming an important parameter when proposing cost-effective solutions within the home environment. The proposed approach issues a combination of organization, design and technology, in order to simplify ADLs while maintain minimization of space utilization requirements.

Ergonomy
Ergonomy is the science of designing user interaction with equipment and workplaces to fit the user. It is all about to get the best of something, but with the smallest effort. Because of the ‘ergonomics’ the sense of function is as much important as the sense of aesthetics. Ergonomics is about creating a product or an environment, where the connection between human skills and the surrounding is optimized. First studies about ergonomy were made in the USA during the industrialization period to optimize the efficiency of the workers. Later on, there were more studies during the world wars to examine efficiency of new and complex machines and weaponry. More researches were made at the BauHaus, a school in Germany that combined crafts and fine arts, and was famous for the approach to design that it publicized and taught. Henry Dreyfuss, one of the celebrity industrial designers of the 1930s and 1940s, was the first who had really consequently studied and also used ergonomy in his design studio. He just did not care about the outward appearance of his products but he also cared about how to use them in a good way.

Outside of the discipline itself, the term ‘ergonomics’ is generally used to refer to physical ergonomics as it relates to the workplace (as in for example ergonomic chairs and keyboards). Ergonomics in the workplace has to do largely with the safety of employees, both long and short-term. Workplaces may either take the reactive or proactive approach when applying ergonomics practices. Reactive ergonomics is when something needs to be fixed, and corrective action is taken. Proactive ergonomics is the process of seeking areas that could be improved and fixing the issues before they become a large problem. Problems may be fixed through equipment design, task design, or environmental design. Equipment design changes the actual, physical devices used by people. Task design changes what people do with the equipment. Environmental design changes the environment in which people work, but not the physical equipment they use.

Fig.1. Applied ergonomy
Current Standards and Problems
A research was performed in order to identify ergonomy in ageing society environments. Elderly people usually apply some degree of ergonomy, by adapting their environment in a way to serve their needs. Thus they usually accumulate less frequently or unwanted items in high, out of reach levels, and more frequently used items in their proximal low level area. Figures 2 and 3 present this observed behavior.

Storage space is, especially for elderly people, a very important requirement, since they accumulate over time a lot of personal items. This occurs due to the fact that very often, items that are forgotten, or not found, are replaced by new ones, resulting thus in excessive storage space loss. It is necessary to improve the accessibility to such items in order to enhance the ability of retrieval and reduce redundancy in storage space utilization.

PROPOSED CONCEPT
In order to efficiently deal on assisting elderly people in retrieving stored items a robotic furniture system is proposed. The conception of the design was influenced by observing the arrangements elderly people follow in their home environment in order provide them with direct access to their frequently used items. Space redundancy is limited by the proposed design approach since the robotic furniture introduces a height adjustable storage solution. A set of electrical motors is used to position the various sections of the system into the correct height level, and to displace them towards the horizontal axis, to allow a rotational motion path, Figure 4.

Elderly people accumulate items they frequently require in their proximal area, due to the fact that they want to allow comfortable and direct access to them, form a sitting posture. Even though the ideal level of storing items is in places that they can be easily retrieved form a standing or sitting position, i.e. between 0.5 to 1.5 m, due to storage space absence, they tend to store items in low level places as well, where they can be not so straightforwardly reached. This introduces some limitations since elderly people face stiffness issues and disabilities. Furniture offering storage space that can be adjusted in height, significantly contributes to overcome such limitations, while offering extreme functionality and ergonomy, utilizing less space compared to conventional storage furniture.

Fig.2. Unused items stored in high, out of reach levels

Fig.3. Accumulation of frequently used items within the proximity and relatively low levels

Fig.4. Rotary Motion Path

The idea is based on adaptive and space-dividing furniture, offering vertical height adjustment, accord-
ing to the user needs. The proposed concept was also considered to be applied in various areas within a home environment. The system can be manufactured and customized according to the required application, such as apartment entrance, living room, kitchen, bathroom, etc. Furthermore, since the robotic furniture is accessible on sides, front and back, it can be used to partition space in an efficient way, introducing a barrier-free approach, assisting in the mobility of elderly people using wheelchairs and rollators, and requiring less space utilization for installation, Figure 5. A saving of up to 20% is estimated compared to a conventional apartment arrangement, since all required functions such as beds, sofas, tables, chairs, etc., can be integrated into the proposed concept, deployed upon request using robotic actuators and sensors, Figure 6.

**Fig.5. Barrier-free design approach offering enhanced space saving**

**SOLUTION APPROACH**

Once conceiving the proposed concept, it was then realized in a 1:1 scale partially functioning prototype to allow evaluation and testing, Figure 7.

A set of motorized servos arrangement is going to be later added to the prototype for the vertical and horizontal displacement of the robotic wall elements, controlled by a microprocessor. Each element then can be transported via a chain type belt, attached to the servo gears. A grid of rail type mechanisms is already implemented to secure the elements and allow a smooth vertical and horizontal translation of each one, leading to a rotational motion path, Figure 8.

**EVALUATION**

The prototype was evaluated in terms of:

- Ergonomy (Using and Age Simulation suite)
- Organizational Ergonomy within a room
- Space Use (as the individual sections/shelves can rotate it is possible to use rooms more in a vertical direction and about 20% space for storage on the ground can be saved and generate free space for mobility with rollators or wheelchairs)

**Fig.6. Proposed concept configurations**

The evaluation using an age simulation suite was performed, Figure 9, in order to simulate the limitations elderly people face in performing simple movements. In order a furniture to provide ergonomic features, it must be designed and manufactured according to a set of standards that would allow unobtrusive access, optimum space utilization and adaptability to the user needs. The evaluation procedure revealed that the proposed furniture design allows direct access, addresses elderly people mo-
bility problems, and enables space utilization saving while maintaining improved functionality.

Fig.7. 1:1 scale implemented prototype

Fig.8. Rotational and translational mechanisms

Fig.9. Evaluation of the robotic furniture system by an age simulation suite

PROPOSED SYSTEM FRAMEWORK

The proposed system architecture is depicted in Figure 10. The human-machine interaction is performed via visual and vocal information exchange between the user and the robotic furniture.

Fig.10. Block diagram of the proposed system framework

A miniPC is used to serve as the main processing unit, interfaced with a Microsoft Kinect Sensor, an Arduino-based microcontroller board driving the motors of the robotic furniture, and a touch screen display which provides an appropriate graphical user interface (GUI) to allow efficient operation of the system.

The user stores and retrieves items via the middle shelf of the robotic furniture. The Kinect Sensor acquires color RGB 640x480 pixels spatial resolution images, of the stored items within the middle shelf.
For evaluation purposes items with different colors were used. Different color items were placed into different shelves of the robotic furniture. In order for the user to retrieve an item, a vocal command is issued corresponding to the required item color. The vocal interpreter is implemented using Microsoft Kinect embedded microphone, which provides voice recognition capabilities. The position control mechanism issues a command to position the correct shelf in the middle position of the furniture in order for the user to retrieve the required item.

The application was programmed using C# programming language, for interfacing the Arduino motor controller board, Microsoft Kinect Sensor, and implementing the required graphical user interface projected to the touch screen display.

RESULTS AND FUTURE DEVELOPMENT

The proposed vision controlled robotic furniture is still under development in order to define final specifications and offered services, and to enhance its functionality and operation towards the user. Currently the vocal user queries are limited to voice commands representing various colors. The vision system acquires an RGB image which is processed and the corresponding item color is extracted, in order to classify the item position in the corresponding robotic furniture shelf. The proposed study aims to integrate a more intelligent visual algorithm, which would classify objects not only according to their color, but to their identity using an object recognition algorithm. Additionally, the Kinect visual sensor is able to acquire depth information, allowing thus multiple items stored in the same shelf to be efficiently detected and identified.

Tests implemented to evaluate system performance presented a real-time response between user queries and resulting signaling commands to the motor drives. Since the tests were conducted by observing the corresponding output signals issued by the Arduino microcontroller board, that are going to be later interfaced to the electrical motor drives, the observed real-time response, efficiently provides a responsive system with minimal error rate. Errors are currently introduced by the voice recognition module, since vocal color commands are sometimes interpreted into the wrong color. This error rate can be eliminated by an appropriate voice recognition training stage, corresponding to a new set of vocal commands that would allow efficient differentiation of user queries.

Additional features such as health monitoring sensors, medication dispenser, deployable seats and tables, are currently considered to be integrated into the robotic furniture. Such an approach can offer an improved service delivery environment, by utilizing a compact and ergonomic furniture terminal, based upon advances in sensors and sensor networks, robotic elements, mechatronic devices, pervasive computing, and artificial intelligence.

CONCLUSIONS

The proposed concept presented in Figure 6, aims in creating a customized environment using several configurations of novel visually controlled robotic furniture system, providing enhanced services to the ageing society, while maintaining ergonomy. Service delivery is important to elderly people since it increases their independence, allows them to remain longer in their homes, and improves their living quality. By distributing intelligent robotic elements within the home environment, daily human life is revolutionized by making people's surroundings flexible and adaptive. In the proposed research, technologies are deployed to make computers disappear in the background, while the human moves into the foreground in complete control of the augmented environment.

The implemented prototype was evaluated in terms of, ergonomics (using an age simulation suite), organizational ergonomy within a room, and space utilization (as the individual sections/shelves can rotate in a vertical direction, the proposed system is possible to be installed in small rooms, achieving a 20% less space utilization usage, in order to allow free space for mobility with rollators or wheelchairs). A vision system integrated on the prototype to perform object recognition, efficiently classifies objects stored into the various system elements, in order to assist the user in retrieving a specific previously stored object, by moving the appropriate section of the furniture into the correct height. The real-time response of the vision system, efficiently addresses the need for short time delay between user queries and system response.

The robotic furniture system can also serve as a lift or seat, or working place for elderly people, efficiently addressing the ageing society issues in living environments by providing extended ergonomy. Fusing functions and services such as infotainment or internet connectivity, also provides extended functionality to the user, once many everyday activities can be dealt with a more efficient way, all from a single terminal.

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An easy handling system for installing heavy glass using human robot cooperation

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Purpose Glass is widely used as finishing material for a good appearance of a building inside and outside. Moreover, the trend is to make this construction material and component larger and heavier. To safely and easily install this heavy duty and fragile glass, we propose an easy handling robot (EHR) system for glass installation work. Method We used an intuitive installation method; robot analysis using robotics; robot design; dynamic analysis using DAFUL. Results & Discussion The EHR-system is divided into mobile, manipulator, and human robot cooperation (HRC) algorithm parts. We designed the mobile and manipulator, we then verified using DAFUL. We verified the HRC-algorithm by experiment. It is expected that the EHR-system will make this type of work easier and safer.

Keywords: robotics, intuitive installation method, virtual axis, robot design, robot analysis

INTRODUCTION Installation work of large outer wall panel glasses such as curtain walls in construction sites is carried out at the border between the inside and outside of a building. This kind of work increases the labor load and stress of workers and the danger of such accidents as falling and crane overturning. Until now, such large glass finishing materials have been installed by workers. Except for the movement of glasses, all the work processes including assembly and installation have depended on workers¹. This is because there is a limitation in completely automating glass installation works (access to the installation position and fitting) in the changeable environment of construction sites. Furthermore, as the high-rise buildings become larger, it is an inevitable trend that such construction materials become larger and heavier, and installations of these materials have naturally increased. Therefore, as a measure to guarantee the safety of construction workers and shorten construction period, semi-automation systems based on human-robot cooperation (HRC) techniques instead of full automation are being developed and applied²~⁴. OKTOPUS by Materials Handling Corp. in Australia, Mobile Ergonomic Handler by Arlington Equipment Corp. in the U.S., Geko & Glass Robot Hire by GGR Corp. in the U.K., and KS Robot 280 by K.Schulten GmbH & Co.KG. In Germany are representative glazing robot systems based on human-robot cooperation technology⁵~⁸. Similarly, Yu et al. in Korea developed a curtain wall robot with a 3DOF manipulator attached to the end-effector of a mini-excavator⁹. For these robots, the operator manipulates the joints of the robots. If unskilled operator uses this robot manipulation method, however, it takes long to work and has a high likelihood of accidents. To address this problem, Lee et al. developed a skylight glass installation robot with 6DOF F/T sensors so that operator can directly operate the robot from the robot end-effector¹⁰. Furthermore, Lee applied force control to promote the safety of workers and protect glasses when operator works from the robot end-effector¹¹. Force control transmits the repulsive power of materials against the environment to the operator so that the operator can safely operate the robot for such tasks as assembly. However, additional problems occurred in actual application such as high sensor cost, calibration of the weight of heavy objects, and the separation of force and torque. Thus, Gil et al. proposed a robot installation method in which the operator defines the rotation axis of the panel glass (virtual axis) and the motion of glasses is determined by the force applied to the rotation axis and the force applied from a point of action on the panel glass¹². This paper describes the design process of the Easy Handling Robot (EHR) system using this method. The design process of EHR is as follows. First, the most appropriate model for EHR system is benchmarked through an analysis of the HRC algorithm which is the glass installation method proposed by Gil et al. and the construction work environment. Then, the permissible torque and speed of each joint is determined through kinematic and static analyses based on the rough appearance and motion of the model. Lastly, the decelerator, motor, and link structure of EHR are designed.
through the defined torque and speed. Figure 1 below illustrates the design process of EHR.

**CONCEPTUAL DESIGN**

Work environment definition

The work environment for installation outer wall glass is shown in Figure 2. The panel glasses are transported to the installing position by passing through narrow passages and doors, rotating in a small space, and avoiding unexpected disturbances. Furthermore, the HRC algorithm proposed by Gil et al. is used.

**HRC algorithm**

The HRC algorithm proposed by Gil et al. is described below. In general, the fundamental study of the HRC algorithm is the motion of a rigid body in space. To make it identical to the actual glass installation method by construction workers, the instantaneous axis of rotation and the point of action of the glass are defined. The robot outputs 6DOF motion from the end-effector that is mapped to the 3DOF linear motion which is inputted from these two axes.

Figure 3 shows the position of the instantaneous axis of rotation and demanded motion for worker to install panel glasses. As shown in Figure 3, the instantaneous axis of rotation changes three times in total until the glass is installed. For demanded motions, 3DOF linear motion (a), 3DOF rotational motion (b), and 1DOF rotational motion(c) are required.

For the DOF and link structure of manipulator, one model of the existing commercial glazing robots was benchmarked considering the motions demanded for installing glasses to the outer wall. In this study, the Geko P+ model of GGR Corp. in the U.K. and the KS Robot 280 model of K.Schulten GmbH & Co.KG. In Germany were compared, and the appropriate model for the EHR system was selected by the following process.

The motion at the time when the panel glass is installed at the installing position is defined as follows. Under the assumption that the worker is working on a flat ground, we need $T_x$, $T_y$, and $T_z$ for 3-axis linear motion, and $R_x$ and $R_y$ for rotational motion. Figure 4 shows the demanded motion of the panel glass, the robot model, and the demanded joint parameters of the two robot models to implement the demanded motion. Here, “passive” means driving by worker with no motor. From Figure 4, we can see that KS 280 is more appropriate for implementing the demanded motion of the panel glass than Geko P+. Therefore, the manipulator of the EHR system benchmarked the KS 280 model.

**Conceptual design**

Based on the work environment, HRC algorithm, and the benchmarking model, the requirements for the EHR system can be summarized as follows:
1. The EHR system must be able to pass through a narrow door or passage during glass transportation.
2. It must be able to rotate in a narrow space.
3. It must be possible to install the panel glass on the outer wall.
4. The manipulator of the EHR system must have 5 DOF.
5. It must include the HRC algorithm.
6. It must benchmark the KS 280 model.

Figure 5 below shows the mobile part of the EHR system to satisfy the above conditions.

The mobile part has three wheels (two fronts and one rear) to enable rotation in a narrow space. The steering wheel is behind the mobile part. The driving wheel is also located at the back to reduce the weight of the mobile part and to facilitate control. To allow the mobile part to pass through narrow passage or door, t is set to 600 mm. Furthermore, to overcome nails and sharp scraps, the front wheels are made of solid rubber.

Fig. 6 Conceptual design of manipulator part

The manipulator part of the EHR system has 5 DOF (PRPRR type) to implement the HRC algorithm as shown in Figure 6. The length of each link of the manipulator is defined by benchmarking KS 280. Considering that this is a prototype and for work safety, the payload of the manipulator was set to 100 kg and the speed at the end-effector was set to 0.03m/s.

**DESIGN OF ROBOT SYSTEM**

This section describes the detailed design of the motor in line with the payload of the manipulator part and the speed of the end-effector.

**Design of manipulator part**

Axes 1 and 3 of the EHR system's manipulator are prismatic and axes 2, 4, and 5 are rotational. First, the axis that receives the largest torque among the rotational axes is 2 which is farthest from the panel glass. Thus, axis 2 was designed as a four bar linkage mechanism using a linear actuator as shown in Figure 7.

In the mechanism in Figure 7, the attachment position of the linear actuator affects the size of the load added to the actuator and the up and down speed of the robot end-effector. Thus, in this study, to minimize the load of the actuator and satisfy the demanded speed of the robot end-effector, the attachment position of the linear actuator was determined using the following optimization conditions.

First, $k_1$ and $k_2$ were defined roughly from the KS 280 model. Furthermore, $\alpha$ was defined by considering the average height of workers at the robot end-effector. The linear actuator must be as vertical to the ground as possible within the defined work range and the ratio of minimum to maximum lengths must not exceed 1.6. From these conditions, the optimization conditions are as follows:

Find $k_1, k_2$

to minimize $F_{max}$

subject to:

$1.1 \leq \frac{L_{max}}{L_{min}} \leq 1.6$

$0.2m \leq l_k \leq 0.45m$

$0.4m \leq \alpha \leq 0.875m$

$-38^\circ \leq \alpha \leq 11^\circ$

$8mm/s \leq v \leq 35mm/s$
From the above conditions, the following equations can be derived:

\[
\begin{align*}
I &= \sqrt{k_1 + 0.26125 - k_2 \cos(\alpha)}^2 + (0.927 + k_2 \sin(\alpha))^2 \\
\gamma &= \alpha \tan(2(p_1(3) - p_2(3), p_1(1) - p_2(1)) - \alpha) \\
F &= \frac{g \cos(\alpha)(M \times l + P \times 2.033)}{k \times \sin(\gamma)} \\
\eta &= \frac{p_2(1) - p_1(1)}{\alpha \times 1000}
\end{align*}
\]

where,

\[
\begin{align*}
p_i(1) &= 0, p_i(2) = 0 \quad p_i(3) = k \cos(\alpha) - 0.26125 \\
p_i(1) &= 0, p_i(2) = 0.927, p_i(3) = 0.927 + k_i \sin(\alpha)
\end{align*}
\]

\[
\begin{align*}
l: \text{length of linear actuator} \\
F: \text{force exerted on linear actuator} \\
v: \text{velocity of linear actuator} \\
l_c: \text{center of upper link} \\
P_e: \text{exerted force on robot end-effector} \\
M: \text{mass of upper link} \\
\omega: \text{angular velocity}
\end{align*}
\]

Using the PQRSRM (progressive quadratic response surface method) of the integrated optimization software PIAnO of FRAMAX Corp., we can derive the design parameters from the above equations as shown in Table 1.

### Table 1 Design parameter of 2nd joint mechanism

<table>
<thead>
<tr>
<th>(k_i)</th>
<th>(k_r)</th>
<th>(r)</th>
<th>(l)</th>
<th>(\eta_\text{in})</th>
<th>(\eta_\text{out})</th>
<th>(v_\text{in})</th>
<th>(v_\text{out})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2m</td>
<td>0.479m</td>
<td>-41.14'</td>
<td>69.57mm</td>
<td>1.688rpm</td>
<td>754.36kN</td>
<td>28.83Nm</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8 Angular velocity of 5th axis

In the case of axis 5, the angular speed is proportionate to the linear speed inputted by operator. If the glass size is 2(m) X 1.8 (m) X 10(t), the linear speed inputted by operator and the angular speed at the axis 5 are as shown in Figure 8.

Furthermore, if the payload of EHR is 100kg, the suction device is about 60kg, and the distance from the axis 5 to the center of gravity of the glass is 240 mm, the torque required for 5 axis is about 377 Nm. In addition, to maintain the current position with the manipulator stopped, the reduction gears of axis 5 are selected in the order of figure 9 to transmit power.

![Motor and reduction of 5th axis](image)

In the above figure, the worm gear model has the permissible torque of 196 Nm at the maximum output of 9 rpm. The reduction ratio of the spur gear is set to 2:1 by comparing the output torque of the worm gear with the maximum permissible torque. Furthermore, considering the efficiency of the worm gear, the reduction ratio of the helical gear and the torque of the DC motor are defined as follows:

\[
\begin{align*}
\tau_{\text{out, hel}} &= \tau_{\text{out, worm}} \cdot R_{\text{hel}} \cdot \lambda_{\text{hel}} \\
\tau_{\text{out, worm}} &= \tau_{\text{out, hel}} \cdot R_{\text{worm}} \cdot \lambda_{\text{worm}} \\
\tau_{\text{out, spur}} &= \tau_{\text{out, worm}} \cdot R_{\text{spur}} \cdot \lambda_{\text{spur}} \\
\tau_{\text{out, worm}} &= \tau_{\text{out, hel}} \cdot R_{\text{worm}} \cdot \lambda_{\text{worm}} \\
\tau_{\text{out, spur}} &= \tau_{\text{out, worm}} \cdot R_{\text{spur}} \cdot \lambda_{\text{spur}} \\
\end{align*}
\]

For axis 4, a chain sprocket and a linear actuator were used to prevent interference with 3 and 5 links and to allow driving with the minimum torque.

![Mechanism of 4th axis](image)

In Figure 10 above, if L is 500 mm and 200 kg is applied, the torque on sprocket 1 is 882 Nm. Considering the number of teeth of sprocket 1 and the minimum fracture load of the chain, the RS50 double-row chain was selected. The force applied to the chain is 23105 N and the number of teeth of sprocket 1 is 15. Furthermore, the number of teeth of
sprocket 2 is set to 23 considering the demanded speed, motor speed, and torque. Axis 1 supports the load of manipulator and glass and implements linear motion. Appropriate parts must be selected considering the moment and friction due to the load. Thus, an LM guide was used to support the load of manipulator and glass and linear motion was enabled using ball screws. The positions of ball screws and motor must not interfere with the mobile platform. Figure 11 below shows the prismatic joint of 1st axis.

![Fig. 11 1st prismatic joint](image)

The permissible torque and speed of axis 1 are defined as follows. If \( N \) is the number of runs, \( L \) is the running distance, and \( v_L \) is the maximum speed,\n
\[
\frac{60}{N} = t_a = \frac{60 \times L}{v_L}
\]

as \( v_L \) is 0.03m/s (1.8m/min),

\[
t_a = \frac{60 \times L}{v_L} = \frac{5 - 60 \times 0.1}{1.8} = 1.7 \text{ sec}
\]

\[
t_c = 5 \times 1.7 \times 2 = 1.6 \text{ sec}
\]

If the external diameter of ball screw is 20mm, and the lead is 5mm, the thrust torque and speed of the ball screw are as follows:

\[
T = \frac{F_a \cdot \text{lead}}{2 \pi \cdot \eta} \cdot \frac{300}{2 \pi} = 0.0078 (Nm)
\]

\[
\text{lead} = \frac{\text{max}}{N_{\text{max}}} = \frac{1.8 (\text{rpm/min})}{0.005 (\text{lead})} = 360 \text{rpm}
\]

Here, \( F_a \) is the vertical load, \( \eta \) is efficiency, and \( \mu \) is the coefficient of friction. In the case of axis 3, the force applied to the prismatic joint varies by the working range of axis 2.

Assuming that there is no friction force and a load of about 200 kg is acting on the robot end-effector, the force applied to the prismatic joint according to the working range of axis 2 can be illustrated as Figure 12 below.

![Fig. 12 3rd prismatic joint](image)

From Figure 12, the force \( F_1 \) on the 3rd prismatic joint can be expressed as follows:

\[
\begin{align*}
\alpha &= 11^\circ \rightarrow F_1 = 374N \\
\alpha &= -38^\circ \rightarrow F_1 = 1207N
\end{align*}
\]

Furthermore, the maximum speed was set to 0.03m/s if only 3 joint is driven.

**Design for assembly**

The EHR system including the motor, reduction gears, and link structures is shown in Figure 13 below.

![Fig. 13 EHR design for assembly](image)

In Figure 13, part A (wheel with driving and steering) and D (suction device) are existing commercial products. Part B is a weight balancer for balancing the center of gravity of the EHR system during work. Part C is an outrigger to prevent the overturning in the transverse direction. Part E is a passive joint to narrow the width of EHR system when passing through a narrow door with a glass attached.

**SIMULATION**

This section describes a simple simulation about overturning with the multi-objet simulation software DAFUL of Virtual Motion. If it is assumed that 100 kg is applied to the robot end-effector, the overturning likelihood of the EHR system can be determined.
through the moment of the front wheels in static situation.
Figure 14 below shows the locations of vertical load on the robot and the acting position.

Fig. 14 Vertical load and position of vertical load

In Figure 14, M₁ is the center of gravity when assuming that the weights of glass, suction device, and axis 5 are acting on the robot end-effector. M₂ is the center of gravity of axes 1-4 and the mobile platform. M₃ is the center of gravity of the weight balancer. Furthermore, M₄ is the center of gravity of part A in Figure 13. The moment acting on the front wheels is as follows:

\[ M = 1400 \times 200 - (350 \times 390 + 970 \times 100 + 1195 \times 140) \]

\[ = -120800 \text{ (kg \cdot mm)} \]

The above result shows that the moment in static situation is negative (-) and stable against overturning. Next, Figure 15 below shows the simulation of a dynamic situation using DAFUL.

Fig. 15 Simulation for dynamic motion

In Figure 15, sections 1-3 show 90° rotation of axis 4, sections 4-7 show 90° rotation of axis 5, and sections 8-10 show the motion of mobile movement. The floor was assumed to be dry asphalt.

The simulations of static and dynamic situations described above show that the EHR system is stable against overturning.

CONCLUSION

Installation of outer wall glasses in construction sites is a type of work with a high risk of accident which causes high labor load and stress to workers. Thus, many glazing robots are being commercialized. This paper described the design of an EHR system that has been improved the problems of such glazing robots and can be used intuitively even by unskilled workers.

The design process of the EHR system was as follows. First, the restraints of the robot system were defined from the construction work environment and the HRC algorithm proposed by Gil et al. Next, based on these restraints, the most appropriate model for the EHR system among the existing glazing robots was benchmarked. Then, the permissible torque and speed of each joint were determined through kinematic and static analyses based on the rough appearance and motion of the model. The permissible torques and speeds of these joints became the restraints for designing the motor, reduction gears, and link mechanisms. The mobile driving parts and suction parts were replaced with commercial products. Finally, the entire system was verified using the multi-object simulation software DAFUL. It was first verified against overturning in static situation and then in dynamic situation. The simulation results showed that the proposed system is stable against overturning during mobile movement. More studies are required in the future to verify the performance of each joint through simulations, the actual application of the robot system, and the proposed HRC algorithm.

ACKNOWLEDGEMENT

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Development of cleaning system installed in horizontal moving system for maintenance of high-rise building

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Purpose

Nowadays, in modern cities many high-rise buildings are equipped with curtain-walls. Before the advent of robot technology, building maintenance experts maintained curtain-walls periodically. However, their work is very dangerous and there are many falls and accidents in the workplace. Because of this danger, the manual maintenance process is very expensive. In order to solve this problem, our paper suggests a full-automatic cleaning system which is installed as a built-in guide rail robot system.

Method

The built-in guide rail robot system consists of two moving systems: a vertical and a horizontal moving system. Especially important is the horizontal moving cleaning system. There are three units in the cleaning system: a roll-brushing unit, an injection unit, and a squeezing unit. These units work in a particular order. Having two moving systems extend the cleaning area, and the vertical moving system is equipped to charge necessary supply material.

Results & Discussion

The design suggested in this paper is suitable for high-rise building maintenance. Not only is this robot is automatically workable, but it also saves maintain building time. Therefore, using this robot, building maintenance is safer and more efficient than using manual labor.

Keywords: building maintenance, cleaning system, material supply

INTRODUCTION

Nowadays, the recent height of buildings in modern cities is increasingly higher. In addition, those buildings have equipped with curtain-walls for beauty. However, dust of cities makes easily façade of curtain-walls dirty.

To prevent façade from being dirty by dust, building maintenance experts should maintain it, usually once per three months. Unfortunately, their work is too dangerous, so there are many fall and crash accidents in the workplace. Because of this danger, their employment fee is too expensive and this increases expense of the manual maintenance process.

In order to solve this problem, many engineers have developed the building maintenance robots to take the place of human labor. Those robots can be classified into two categories based on direction of maintenance: rooftop gantry type, and built-in guide rail type.

The first robot maintains façade with moving vertically by hanging on the rooftop gantry. This robot is able to clean flat surface efficiently. However, on curved surface, this robot cannot be attached perfectly, and that causes poor efficiency of maintenance work at curved surface.

Unlike the first type, the second robot cleans façade with moving along the horizontal rail that is installed in building. Not only to move horizontally, but this system also is able to move vertically by combination with vertical moving system. Additionally, it can be attached more closely at curved surface than the first.

By this fact, efficiency of maintenance work on curved surface is almost constant, comparing with on flat surface. That is, the built-in guide rail type is more suitable for all-area cleaning than rooftop gantry type.

In order to replace completely the human labor by maintenance robot, with suitable type for maintenance work, development of full-automation of cleaning system is also needed, because the existing maintenance robot is semi-automatic in material charging work, and cleaning work.

So, this paper deals with the full-automatic cleaning system and material charging system. The cleaning system is installed in the horizontal moving system, and is supplied with maintenance materials from the material charging system installed in the vertical
moving system. The overall design concept and the integrated control algorithm about the cleaning system and material charging system will be introduced. The robot used in this paper is a prototype for experiment. To determine briefly how this robot is applied in real building, this paper uses it with the test-bed building.

**BUILDING MAINTENANCE ROBOT BASED ON BUILT-IN GUIDE RAIL**

As mentioned previously, the building maintenance robot in this paper moves along the built-in guide rail which consists of vertical and horizontal one. As the built-in guide rail can be divided with install direction, the robot also has two systems classified by moving direction: the horizontal moving system, and the vertical moving system.

The system which do mainly maintenance work is the horizontal moving system. Its moving mechanism called wheel mechanism\(^5,6\) makes it move along the horizontal rail without separation. In the wheel mechanism, the encoders are attached to the motors, or directly to the wheels, in order to get information of location.

For smooth movement, anti-shock mechanism\(^5,6\) is installed, and it is to prevent the horizontal moving system from destroyed by shock and vibration, which is generated by installation error of rail. Moreover, for moving smoothly in curved rail, there is the curve moving mechanism\(^5,6\).

The vertical moving system uses inch-worm mechanism and hook mechanism for vertical climbing\(^6\). Especially, those two systems help to move up and down more precisely than the rooftop gantry type which uses gondola-winch system.

Using those mechanisms, the vertical moving system is to carry the horizontal moving system to the next floor and charge storage with maintenance material. However, before two works, combination of two systems should be followed. For this combination, the vertical moving system of the robot has the compact docking mechanism. It is operated by only one motor. But nevertheless, it can make two motions that are docking and pulling/pushing, by using relative motion between links of it\(^6\). When the robot comes in the next floor and the horizontal moving...
system prepares to enter the horizontal rail of that floor, the separation, whose operation order is contrary to combination, begins. In this way, the compact docking mechanism makes it possible for the vertical moving system to do two aforementioned works. Specifically saying about how the compact docking mechanism helps to charge storage with material, proper connection between the storage and material charging system is made by exact combination of two systems.

**MATERIAL CHARGING SYSTEM**

For full automation of the maintenance work, charging maintenance material should be automatic. The existing maintenance robots charge material periodically by manual charging work. But, that case takes too long time, because of manual work. So, for the robot to supply material to its storage by itself, in this paper, material charging system is developed. It has benefit that light weight of the robot is possible, because size of storage of maintenance material can be small, and save work time. For safety, charging work should be processed with satisfying that the additional force, which is made in charging work, should not be over the required amount. Under consideration of that, this paper uses 2 stage-station of valve system. It consists of two systems that are ‘Automatic-Water Dispensing System’, and ‘Transmitted Operation Material Supply System’. The first system is automatic and safe connection mechanism between the material source of the building and the material charging system. The second one is connection between the material charging system and the storage of the horizontal moving system.

In automatic-water dispensing system, there is linear actuator which consists of motor, pulley, and linear guide. It makes connector, which is the hose centered in steel cylinder, dock with electromagnetic fitting part by magnetic force, and be connected with electric valve of fitting part. In order to protect façade from damage in connection, the linear actuator constrains sudden strike by moving smoothly. During connection, the push-lock switches embedded in the fitting part are pressed and pump is operated, and then electric valve is opened. The transmitted operation material supply system is simple connection that uses only one pump and bucket. The small opened bucket is installed in the horizontal moving system, so when combination between the horizontal moving system and the vertical moving system is completed and then pump is
operated, material flow into it. The bucket is just connected with the storage, material flows again into the storage through pump.
When charging is completed, the connection between the fitting part and the connector by magnetic force is released. Next, the pump loses power, and the electric valve is closed. All those processes are presented in algorithm flowchart of Fig.8.

CLEANING SYSTEM
After supplied from the material charging system to the storage, the cleaning material is stored temporarily in the storage, and then flows to the cleaning system through pump, when the cleaning system starts maintenance work.
The cleaning system is only part that is able to do maintenance work in this robot. So, it should be designed to optimize efficiency of maintenance work. For that case, using simple maintenance mechanism, it saves electric energy by using few actuators. Also, it can simultaneously take care of moving along the rail and maintaining the façade. Thanks to that, time for the maintenance work can be less than conventional method.
The cleaning system consists of three units: Roll-brushing unit, Injection unit, and Squeezing unit. Those units are aligned horizontally, and installed in order which is determined by order of usual cleaning work.

1. Roll-Brushing unit
The roll-brushing unit accesses the target cleaning area firstly. In usual cleaning work, sweeping is the first process that is to remove bigger dust before wiping. Roll-brushing unit is to sweep bigger dust attached at the façade of building. Its sweeping type is rotation-sweeping that is operated by motor. In addition, size of the roll-brushing unit, especially about diameter of roll brush, is determined to not intercept nozzle’s injection range.

2. Injection unit
After the roll-brushing unit sweeps target cleaning area, the injection unit accesses it secondly. Nozzles of this unit are supplied with maintenance material in storage, and inject it to the façade. This unit is assembled with the roll-brushing unit, so if it comes close to the obstacles like mullion, it will go inside the horizontal moving system with the roll-brushing unit. The reason why it is connected with the roll-brushing unit is that the roll-brushing unit is to not intercept nozzle’s range of injection.

3. Squeezing unit
The injected water separates the small dust or stain which is not removed by the roll-brushing unit. The squeezing unit removes water that is polluted by small dust and stain. In order to do that without collision, it also has linear motion that move inside and outside the robot, by linear actuator, which consists of motor and linear guide. Like the preceding two units, it is able to avoid crash with obstacles, by moving inside the robot. On the contrary to that, with moving outside the robot, it can remove perfectly dirty water by rubbing the façade with pressing properly it.
INTEGRATED CONTROL ALGORITHM

For all part of the robot to co-operate harmoniously, control system should give the instruction to each part through control-center. Desired instruction for maintenance work is transferred to the vertical moving system through the wireless modem from the control center.

First, the instruction transferred to the vertical moving system is about its vertical climbing. It carries the horizontal moving system to target floor for maintenance. When the vertical moving system arrives at target floor, control-center gives the vertical moving system an instruction to operate material charging system.

After the instruction is transferred to the control system of the vertical moving system, the control system transfers signal for linear actuator of the material charging system to have the connector approach the electromagnetic fitting part. When connection with material source is completed, the control system orders pump and solenoid valve to operate. So, when the solenoid valve opens, the pump gives force for material to flow into the storage.

When the storage of the horizontal moving system is full of material, flow-meter and timer give information about that to the control center. After that, combination by the docking system is released by docking release signal of control center. Then, the control center orders the horizontal moving system to start maintenance work.

When maintenance work in process, the pump and solenoid valve which are installed in the horizontal moving system operate for material in storage to flow to nozzles of the injection unit.

In the maintenance work, when the contact sensor detects obstacles like mullion, information of the contact sensor is delivered to the control board which is installed in the horizontal moving system. And then, the control board orders that linear actuators have the units of the cleaning system move inside.

Specifically saying about avoidance process, when the roll-brushing unit nears obstacle, the roll-brushing unit and the injection unit move inside, while nozzles of the injection unit keep injecting material to the facade. When the roll brushing unit pass exactly obstacle, two units move outside, in order to sweep small area near obstacle. Although the injection unit doesn’t pass obstacle completely in that time, there is no smash between façade and injection unit. The reason is that the injection unit is designed more inward than the roll brushing unit. Meanwhile, the squeezing unit also conducts same process.

When the maintenance work is completed, encoders give distance information to the control center, and then control center confirm that the horizontal moving system arrives at the end, by calculating position of the robot with distance information. The control center, then, sends a return order to it. Finally next-floor transportation work is carried on.

By repeating these processes, the maintenance robot is able to maintenance all area of the building.

CONCLUSION

This paper describes a new type of the building maintenance robot system whose movement is based on the built-in guide rail type, and deals with the material maintenance and the cleaning system. By the wheel mechanism, the curve moving mechanism, and the anti-shock mechanism, the horizontal moving system can move smoothly along the horizontal rail and also the curved rail without damage. Not only moving horizontally, but moving vertically is also possible by combination between the horizontal moving system and the vertical moving system. The combination can be made by compact docking system. Additionally, in the vertical moving system, it has the inch-worm system using hook mechanism, in order to realize precise vertical climbing.

For stable maintenance work, material supplying is to be stable. So, the robot uses the material charging system. In order to gain high efficiency of mainte-
nance work, the cleaning system is developed into simple mechanism. Furthermore, in order to apply perfectly this robot’s mechanism to the workplace, detail design should be made and data of damage caused by external force also should be gained. This prototype robot will answer how those works will be conducted.

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References
Maintenance robot for wind power blade cleaning

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Purpose Recently, wind power systems have increased in size as a function of economics of scale and they have become large offshore complexes. Approaching a wind power blade is very hard because not only are the blades set up at the sea but also the winds are very high. Nowadays wind power blades are cleaned by people using ropes and a small water jet. The operation is dangerous and inefficient. Therefore, we need a robot for blade maintenance. Method In order to keep the wind power system reliably in operation, both the moving robot mechanism on the blade’s curved surface and the blade-clean-up mechanism for maintenance repair are needed. The moving robot mechanism on the blade’s curved surface looks like INCHWorm, and it can move vertically on the blade. The vertical moving robot is loaded with a clean-up robotic mechanism. The blade clean-up mechanism on the vertical moving robot can clean the blade surface using a water jet, and brush. The water jet sprinkles water on the blade and cleans the surfaces. The brush moves horizontally and cleans the blade curve surface. Results & Discussion This paper suggests the blade-clean-up mechanism robot for maintenance of wind power blades. Not only is this robot automatically workable for blade cleaning, but it also saves time.

Keywords: maintenance, cleaning, robot, rotor blade, wind power system

INTRODUCTION
Due to the declining reserve of the oil and accelerating global warming, people started developing various kinds of alternative energy. Among them, the wind power generation is in the spotlight now because, unlike existing generation systems which use fossil fuels or uranium, it is free from air pollution or radiation leakage. This is because the power source of the wind power generation is wind itself, which never gets exhausted and is obviously environmentally-friendly. Capacity of the Wind power generator around the world is growing gradually, as statistics show at Figure 1. This implies both the number and the scale of wind power plants are on increase. While demand of the wind power plant grew, needs for power plant management and cleaning services also rose. Wind power farms these days are moving from lands to offshore regions because winds are stronger and more spaces are available for the construction of power plants at offshore areas. However, management and cleaning of the power plants become hard due to the decreased accessibility when aerogenerators are located offshore areas. Therefore a robot system which automatically cleans and maintains the wind power blades is needed to improve efficiency and safety.

To solve this problem, various researches are in progress right now. One of those researches are RIWEA robot made by Norbert Elkmann. RIWEA robot inspects the blade by using thermographs, ultra sonic, and high resolution camera, then analyzes its status by digits collected from inspection process. Furthermore, RIWEA robot can inspect bonded spar joints, leading edges, and trailing edges by using non-destructive inspection system. RIWEA robot can be utilized in blade cleaning because the robot can be fastened to the surface of the blade, regardless of the figure, and can move the blades using wire. RIWEA is an open frame concept robot which uses four ropes to move up and down. It has five main parts automatically adjust to the blade surface during its move. However, there are chances where RIWEA robot can misjudge contaminated parts of the blade as cracks. ‘Extreme Wind Services’ of British company is a blade cleaning robot that already exists. Extreme Wind Services use brush, water jet, and camera to clean...
blades. However, Extreme Wind Services requires cranes at ground and needs personnel to control it.

![Dirt Affected Blade](image)

**Fig. 2. Dirt Affected Blade**

Dirt covering the blade can affect aerodynamic performance of it. Fig. 2 shows a bug on the blade. This picture was taken at Magallon26 wind power farm on May, 2005. This single bug can cause double stall effect, which leads to partial loss of theoretical power production [Fig. 3]. This 'dirt' includes flying plankton, mosquitoes, oil, ice, dust, marine salt.

Lengths of the blade are getting longer and locations of it are moving toward offshore areas rather than the lands. However, offshore areas make it harder to clean blades because of the accessibility.

The main purpose of the blade robot designed in this paper is to clean the blades. Those parts that require extra attention are making the robot adjust to the curved configurations of the blade. The robot soaks dirt in water by using water jet and cleans the surface using brush. The water jet can also eliminate certain dirt, and thus makes the process more efficient. In order to move vertically, the robot fastens the wire to brush frame and use crane in nacelle to move. Brush, moving left and right at the brush frame allows the robot to move horizontally. RIWEA is focused on inspection blade. But Blade Cleaning Robot in this paper is focused on cleaning blade. Therefore Robot’s cleaning function was designed more efficient then RIWEA.

![Wind Power Blade Cleaning of Existing](image)

**WIND POWER BLADE CLEANING OF EXISTING**

(a) Manual Cleaning

(b) BladeCleaning

(c) EXTREME Wind Services

**Fig. 4. Wind Power Blade Cleaning of existing**

A person climbs up and uses water jet to do the manual cleaning as showed in Fig.4-(a). A person tides the wire through the nacelle and uses the wire to move the blade up and down. Turbine should be stopped and no wind should be blowing at this moment. At least 3 personnel are needed at this cleaning process. It takes 4 hours to clean each blade. Losing power is caused due to the stoppage of turbine while cleaning. Lots of jeopardies exist in this cleaning process, so labor costs are expensive. Furthermore, the capacity and tools of the personnel could affect the result.

Fig. 4-(b) shows another method of cleaning, Install a water hose on the pillar, and spray water with detergent. While blade rotates, dirt on its surface would move toward the blade tip by the drag effect. Therefore, the blade gets cleaned. However, a pump is required to pump up all the water from ground to wind power rotor through the pillar. Water moves by centrifugal force which is formed by the rotation of
blade so flow of the water is slow. Therefore this cleaning method is somewhat limited.

Extreme Wind Services can do video analysis, cleaning, non-destructive testing, and blade repair by using crane at ground\(^8\). Fig. 4-(c) shows it. The brush to blade pressure is closely monitored using laser sensors; this is so that the brush pressure against the blade is applied. Range of the cleaning differs due to the size of the blade, as cleaning tools go up by the cranes. There could be safety problems as personnel should board on the crane and control it.

**BLADE CLEANING ROBOT**

Blade cleaning robot is composed of side brush frame, leading edge brush frame, camera, water tank, water jet, wire rope holder, roller shock absorber, and brush (Fig. 5).

Leading edge frame is a frame that guides the brush that cleans leading edge part of the blade. Side brush frame is a frame that guides the brush that cleans both sides of the blade. There are all 3 of them. Cameras are located 1 at the leading edge brush frame, and two at the side brush frame. Water that the brush and water jet use are from water tank, and the limit is up to 350L. 4 Water jets are in 1 brush module. There are all 6 brushes, 2 brushes at each frame. There are all 4 Wire rope holders at frame side. Wire ropes use hoist at the nacelle to move the robot up and down. There are all 3 roller shock absorbers at the middle of the frame. The roller shock absorber consists of rubber roller, absorber and spring.

**1. Procedure of cleaning**

Blade cleaning robot goes up by dropping 4 ropes from nacelle down the power generator and connecting them to the wire rope holder. If the blade is located on land, personnel will do the connection at the ground. If the blade is located on offshore, personnel will do the connection at the deck. When the roller shock absorber is well slung over the fins of the blade, in order to figure out the location, starting point of the rope should be marked. Robot goes up spraying water overall using water jet. Brush cleans the surface of the blade using water from the water jet. It goes up checking the condition, whether it is well cleaned and whether there are any cracks on the surface of the blades. If the robot detects any cracks, it memorizes the height by counting the number of hoist rope rotation. If it gets to the blade tip or the base, the primary procedure is done. The robot goes down untying rope, which is the start of the secondary procedure. The robot remembers the condition of the blade at the primary procedure, and goes down to the parts that need to be cleaned more. When it gets down, it starts the secondary cleaning. The robot can go up the 5MW level blade (65m~70m) in about 12 minutes, as it can move vertically 0.1m/s. Each desorption and installation of the blade take 20 minutes, so considering all the time that procedure needs, it only takes 64 minutes per 1 blade to finish the cleaning procedure. This is possible that cleaning time save 3 hours than manual cleaning.

**2. Part Concept Design**

**2.1 Roller Shock Absorber**

Roller shock absorber offsets the vibration which is caused when the robot moves vertically by the rope. It prevents the blade from any damage, which can be caused if the wind blows and the robot wobbles so frame crashes into the blade. Shock absorber weighs from 440kg to 145,000kg. Absorber and spring are attached right down the leading edge brush frame and side brush frame so that it can move vertically, maintaining certain space between itself and the blade figure. Furthermore it uses rubber roller to prevent any damage to the blade when moving up and down.

**2.2 Brush- Water Jet Module**

There are all 3 brush-water jet module, 1 module at each leading edge brush frame and side brush frame. There are 2 brushes and 4 water jet nozzle at brush-water jet module. Injection pressure of the water jet can be regulated from 0 to 145 bar and make it possible to clean certain contaminated areas intensively at the secondary cleaning procedure. When at the middle of the secondary cleaning procedure, only 1 out of 4 water jets is used. Brush is made up of nylon, which don’t damage the blade surface. DC motor, rotating 120 RPM drives the brush. Razor sensor makes it possible to maintain certain space between the module and the blade so that the robot can clean all part equally.

**2.3 Frame Moving of Brush**

Show the brush-water jet module moving the frame horizontally. Use distance measuring sensor and motor to make each brush-water jet module to go back and forth the frame 3 times a minute, taking 4 pillar frames as the standard. The robot can cover the whole surface of the blade because the robot moves...
vertically and brush-water jet module moves horizontally.

![Diagram](image_url)

(a) Roller Shock Absorber  
(b) Brush-Water Jet Module  
(c) Frame Moving of Brush  
(d) View Angle of Camera

2.4 Camera
Of all the 3 cameras, show the camera which is located upside of the leading edge brush frame [Fig.6-(d)]. It checks the condition of the blade surface real-time during moving 150 angle. Control Director using the unaided eye is check the vision data that is send by camera. and he send the interrupt signal about any crack or portions that need extra cleaning. If it detects any crack or portions that need extra cleaning, it marks the location using the number of the hoist rotation and length of the rope. This makes the procedure more effective in time as it remembers the region that needs extra care. There don’t need to vision algorithm because of using unaided eye.

2.5 Rope Holder
Connect the rope to the rope holder and make it possible that the robot moves vertically through the crane. When pulling the rope to the hoist, measure the rotation of the hoist and check the length change of the rope thus marking the robot’s location. The robot weighs almost 1.5t, including water tank, frames, and other components. Wire rope is designed as to endure about 6 ton because of applying quadruple safety factor. Wire rope should be designed 10mm in diameter.

![Diagram](image_url)

Fig. 7. General Application Figure

CONTROLLER
Blade cleaning robot needs 19 motors[Fig 8]. 6 brush rotating motors, 3 brush vertical movement motors, 3 water jet turning angle regulating motor, 4 hoist motion motors. Vertical movement of the blade uses 4 motors in the nacelle and lift up 4 wire ropes simultaneously. All 9 sensors are needed, and razor sensor and distance measuring sensor are used. Razor sensor is used to maintain the distance between brush and the blade surface. Distance measuring sensor is used to measure the distance between brush-water jet module and pillar frame, preventing any crashes between them. Control of the integration motor is done by 1 PLC controller and uses 3 microcontrollers, 1 controller at each frame. Microcontroller takes charge of the rotation of brush, movement of the camera, operation of the water jet. It also takes charge of the movement of the module by reading the numbers on the distance measuring sensor. PLC controller synchronizes 3 microcontrollers, and control hoist of the nacelle to control vertical movement. It saves the
crack detection interrupt of Control Director with the hoist encoder data. CAN (Controller Area Network) is used between the PLC controller and the microcontroller.

![PLC Control Diagram]

**Fig. 8. PLC Control Diagram**

**CONCLUSION**

If the blade cleaning robot becomes commercialized, no more man power could be needed. The robot will also reduce the time of the cleaning and improve the safety as well. Furthermore, aerodynamic performance will be improved so the overall amount and efficiency of the electricity generation would be advanced. If a method that minimizes the amount of the water used at the water jet and the brush and at the same time eliminate the dirt efficiently is developed, it could be possible to downsize the water tank and reduce the weight of the robot. Extra inspection methods, like ultrasound scanning, can be added to more precisely check cracked areas of the blade. Develop packages of 1 cleaning & maintaining robot to every wind power generator and secure some space down the pillar to keep the robot, inspection and cleaning could be done more often and the time needed to install and move the robot could be reduced.

**ACKNOWLEDGEMENT**

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Height Estimation of Gondola-typed Facade Robot

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\textbf{Purpose} We researched an automated and robotic facade maintenance robot. This robot can protect people against safety hazards, and save labour cost for building facade maintenance. Our platform is gondola type. Accurate and robust height estimation is necessary for automation. We propose a methodology for height estimation. \textbf{Method} Even though there are many sensor systems for height estimation, a new design for a gondola-typed robot was needed. Our goal was to make this sensor for the gondola accurate, robust, and cheap. We used a dome camera mechanism with tilt sensors. A range sensor always points vertically to the ground. An estimation algorithm then simulated various situations. \textbf{Results & Discussion} We will present our results in a graph and/or table (Figure 2) and describe and discuss them briefly. We used a Kalman-filter frame to estimate the height of gondola. The concept of monoSLAM was then applied. There is a control update phase and measurement update phase. For control update, the velocity of the gondola cage was also estimated. During the measurement update, there are branches for any obstacles under the sensor. For example, a worker can go under the gondola, construction materials can be laid, and the terrain under the gondola fluctuates.

\textbf{Keywords:} robotics, gondola, facade, maintenance, height estimation

\textbf{INTRODUCTION} The robotic system for building façade is a good example of a robot substituted for human workers in dangerous and poor working places. Many human workers have fallen from building façade, and their stress from the fear of high place in the air is very severe. The robot with intelligent system is free from these threats. The system in this paper is a gondola typed robot. The strong point of this type is that it can be installed at building without intension about robots. The built-in type robot needs special guide rails on the building walls. For automation of the robot system on the building façade, sensors for pose and localization is required. Many application of the robot needs the pose and localization information. For example, paint should be spread evenly. If human worker paints, the person recognizes the state of the wall, and adjusts the amount of the paint. Similarly, the robot also controls the amount of the paint spread on the wall. The pose and location of the gondola cage is an important factor for the control. In this paper, we proposed the methodology of height estimation as a component of the pose and localization sensor system. A range sensor points the direction perpendicular to the ground. The direction is defined by an attitude reference system (ARS). The ARS is a sensor system providing the roll and pitch values. Additionally, a Kalman filter is applied to estimate the height. The filter define has a scenario that such an object come under the sensor temporary.

\textbf{POSE AND LOCALIZATION OF GONDOLA ROBOT} The gondola robot executes intelligent jobs using pose and localization information. We have proposed sensor systems for pose estimation. The pose means the roll, pitch, and yaw of the gondola cage relative to the building façade. However, the gondola robot keeps the contact to the building façade. If the contact is lost, the gondola will pause the operation until the abnormal status is finished. Two suction fans are installed at the lower part of the gondola cage, and keep the contact. Therefore, the rolling is critical pose. Height of the gondola is the distance from the ground to the gondola cage. The movement of the gondola depends on this height information. The main operations are executed while the gondola moves from top to bottom on the building façade. Therefore, moving the gondola cage to the top of the façade is important. At near the bottom of the building façade, deceleration for safe landing of the gondola should be guaranteed. Especially, landscaping works around the building are protected from the gondola robot operations. Additionally, color change in accordance with building height can be expected. In our scenarios, the gondola robot on the building façade is supplied only with power and communications. A paint tank is equipped the lower part of the gondola cage. Therefore, consumption of the paint varies the mass distribution of the gondola. Therefore, intelligent and online sensing and control of the pose and localization of the gondola is important.
RANGE SENSOR BASED HEIGHT ESTIMATION

There are some kinds of height estimation method used in many areas. Airplane systems use two approaches. At higher flight altitude, barometer based system measures it. Its degree of precision is one meter. It is suitable for the airplane, and mountaineers and mountain bike riders use this system. However, the height of barometer is the distance from the standard datum of leveling. In other words, a huge mountain under the airplane cannot be recognized with barometer. Therefore, at lower flight altitude, radio altimeter is used. It measures the time of radio echo. This device measures the distance between the object and the ground. However, this device is military or aerospace product. It is not suitable for the gondola robot system.

In this paper, we proposed a sensor system using a range sensor. It can measure about 100 meter maximum, and the precision is about one centimeter. Because the height of building floor is generally less than three meter, this sensor can cover at least 30 floors.

The problem of this range sensor is that the pose of gondola fluctuates. If the range sensor is installed under the bottom of the gondola cage in direction of the vertical column of the cage, the direction of the range sensor is changed as the pose of gondola rotates. The returned distance of the range sensor is not the height of the gondola cage. It is the distance to the off-site ground from the foot of perpendicular of gondola cage.

To solve this problem, we design a pan-tilt module to support the range sensor as shown in figure 1. Figure 1 (d) is the range sensor. It always points the ground in direction of the gravity. The direction is defined by feedback control from the ARS sensor (figure 1 (e)). The ARS sensor measures the roll and pitch. Panning and tilting modules conduct feedback control to maintain zero roll and zero pitch. Because of this sensor system, the range sensor can always measure the exact height between the gondola cage and the ground.

KALMAN FILTER DESIGN

The measured height of proposed sensor system can be used as deterministic height of the gondola cage. However, this approach has two week points. First, the raw data from range sensor can contain sensor noise. Second, some objects can go under the sensor system. For example, a worker may put construction materials such as pipes and bricks. Many vehicles move in sites. If the range sensor value decreases one meter rapidly, we can guess the reason such as a forklift under the gondola cage. However, the robot system may recognize it as the gondola height decrease one meter below. Landscaping works is another good cause for this rapid height change. If the point of the range sensor system goes from the ground to the top of a tree, it is not change of the gondola cage height.

Basically, we adopt basic design of the Kalman filter. There is control update (prediction) phase, and measurement update (correction) phase. Before the measurement update, current sensor data is compared with former sensor data as shown in figure 2. If the change of the sensor data is bigger than threshold, the Kalman filter recognizes the sensor data gap as an obstacle height. From next filtering, the obstacle height is added to returned sensor data. This state is released when the sensor data is changed rapidly about the obstacle height. It means the obstacles are moved, and the sensor system begins to point the ground again. Note that from first recognition of the obstacle, the gondola cage can move. The release threshold needs margin in comparison to the obstacle height threshold. We use 70% as a ratio to the obstacle height threshold.
As Kalman filter state, the tracked component is the gondola cage height $x_t$ and velocity $v_t$.

$$X_t = \begin{bmatrix} x_t \\ v_t \end{bmatrix} \tag{1}$$

The reason for including velocity $v_t$ to state $X_t$ is that the gondola is expected to keep the equal speed movement downward. The exact velocity should be measured with high accuracy.

The equation from $X_{t-1}$ to $X_t$ is

$$\begin{bmatrix} x_t \\ v_t \end{bmatrix} = \begin{bmatrix} x_{t-1} + u_t^v \Delta t \\ u_t^v \end{bmatrix} \tag{2}$$

$u_t^v$ is the velocity control input. $\Delta t$ is the sampling time for the Kalman filter. As mentioned before, the movement control of the gondola cage is based on the velocity. The control input is also a target velocity. $u_t^v$ is measured by encoders on wire ropes of the gondola system.

$$u_t^v = \frac{e_t - e_{t-1}}{\Delta t} \tag{3}$$

$e_t$ is current encoder value, and $e_{t-1}$ is former encoder value. As shown in mobile robot research, encoder system noise is accumulated. Therefore, the encoder value is converted to velocity information, not distance information.

Figure 3 is Gondola vertical localization sensor on wire rope. It is an encoder with supporting links.

The measurement $Z_t$ is

$$Z_t = \begin{bmatrix} z_t^x \\ z_t^v \end{bmatrix} = \begin{bmatrix} x_t \\ v_t \end{bmatrix} \tag{4}$$

The sensor data from the range sensor is changed to gondola height information $z_t^x$ and velocity information $z_t^v$.

In order to input (2) and (4) to Kalman filter, they can be rewrite as

$$\begin{bmatrix} x_t \\ v_t \\ z_t^x \\ z_t^v \end{bmatrix} = \begin{bmatrix} 1 & 0 & x_{t-1} \\ 0 & 0 & v_{t-1} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta t \\ u_t^v \\ x_t \end{bmatrix} + \begin{bmatrix} \Delta t \\ 1 \end{bmatrix} \begin{bmatrix} u_t^v \\ u_t^v \end{bmatrix} \tag{5}$$

**EXPERIMENT**

MATLAB simulation was designed to verify the proposed Kalman filter modification. The scenario is that the gondola moved from 300 cm high to 60 cm high. 20 cm obstacle and 30 cm obstacle was placed under the gondola one by one. Figure 4 is the height and sensor value graph for this scenario. The sensor data is adjusted to height value to compare with the true gondola height. The red dashed line at bottom part of the graph is the obstacle height. From 7 sec to 13 sec, there was a 20 cm obstacle, and from 23 sec to 27 sec, it is a 30 cm obstacle. The range sensor value mirrors these obstacle heights, so the blue solid line has hollow sections which coincide with the
obstacles. However, the real gondola height does not have such hollow sections as shown with the black dash-dot line of figure 4.

Fig.4. Simulation Environment

The velocity input from user or upper controller is shown in figure 5 (a). Because the input is described with number, the velocity input graph is trapezoidal. This input (red solid line) is converted with sigmoid function in order to change to real velocity of the gondola system (blue dashed line). Figure 5 (b) is the corresponding position, velocity and acceleration graph about this converting.

With sensor data of figure 4 and velocity input of figure 5, the Kalman filter estimated the gondola height. Figure 6 is its output. The top graph of figure 6 is the true gondola height. The middle graph has blue and red graph. The blue solid line is unfiltered height that range sensor data is converted. If the sensor data is 300 cm, the height is confirmed as 300 cm straightforwardly. However, the red dotted line is the output of Kalman filter proposed in this paper. The obstacle is recognized by rigid change of the range sensor value. Therefore there is no hollow section. The bottom graph is the error. The error is calculated by subtracting the true height (top graph) from sensed and filtered height (middle graph). Note that the hollow sections become large error sections. Statistically, the mean and the standard deviation of straightforward height sensing is -7.94 cm and 11.67 cm, respectively. On the other hand, the proposed Kalman filter reduce them to 1.74 cm and 0.91 cm.
CONCLUSION

The proposed sensor system is for the gondola height estimation. Pan-tilt module with ARS makes the range sensor point to direction perpendicular to ground (gravity direction). Sometimes, some objects such as vehicles and trees may corrupt this sensor value. Therefore, we suggest modified Kalman filter to estimate the height.

As future work, we will apply this sensor system to the gondola, and test at 20 meter or higher building.

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References

Advanced Building Engineering: Deploying Mechatronics and Robotics in Architecture

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Purpose
As robots are not yet widely accepted in Europe as service providers in home environments, the authors intend to establish the possibility to distribute robotic elements and mechatronic devices in order to fuse them with various subsystems of buildings. Thus, robotic service systems could support Activities of Daily Living (ADLs), becoming an invisible part of the building. The proposed approach combines and applies strategies of performance oriented architecture 1, ubiquitous computing 2 and service robotics 3.

Method
Buildings and environments consist of a multitude of subsystems as for example walls, ceilings, furniture, service cores and many others. In order to realize the proposed vision of seamless robotic assistance, the authors, since 2008, extensively studied various subsystems, exploring how these could be fused with mechatronic and robotic elements. Currently, the research team enters Step 2 (Table 1). In the proposed paper, building subsystems that had been experimentally fused with mechatronic and robotic elements during Step 1 are described and evaluated. For each category, the authors present their implemented system, embedded into a 1:1 scale prototype experimental flat, which was developed for the realization of the proposed robotic environment. Additionally, the paper outlines: a) how the systems can support ADLs, b) architectural aspects, c) deployed sensor-actuator systems and d) the use of other basic technologies (Vision systems, Robot Operating System: ROS, etc.) during implementation.

Results & Discussion
The evaluations showed that the fusion of building subsystems with robotic technology, in each category (Wall, Ceiling, Service Core, Cabinet, Seat, In-House Mobility – Table 1), holds the potential to create assistive systems that are acceptable in the home environment, and moreover able to assist a multitude of ADLs. The evaluations also revealed that modularity and safety issues should be addressed intensively in future research. The author’s ultimate goal is to explore more building subsystems and finally integrate all systems explored during step 1 and step 2 to an integrated robotic environment in step 3.

Keywords: housing & daily living, service robotics, ADLs, vision systems, robotic room

INTRODUCTION
Experts and masterminds as for example Bill Gates announce the era of service robotics and estimate that service robotics as part of assisted environments will, also because of demographic changes, undergo a similar fast and rigid development as the spread of personal computers in private and economic areas since the 1990s. Already in 1961 Joe Engelberger wondered if relegating robotic technologies explicitly to industrial applications make sense. "The biggest market will be service robots" 4 asserted Engelberger, who started the industrial robotics era when his firm (Unimation) delivered GM’s first robot. Today, robots and distributed robotic subsystems start to permeate our every day surrounding, homes and city environment enhancing them with services and additional performance. At the same time, this permeation is on the way to transform our perception of what robots are, robot technology, robot possibilities and the environment they are merged with. This transformation which has to be understood as a natural part of the evolution of robotics will especially become visible when robots enter the field of service and assistance. Therefore, this article examines new fields of applications for robotics in assistive environments and accompanying transformations. In order to enhance the acceptance of service robotics the proposed approach follows a heavy distribution of sensor-actuator systems into environments and integrates robotic service systems in a seamless or even invisible manner.

Literature Review
Since the 1980s several research groups have created environments and prototype buildings for so-called smart buildings. Based on Ken Sakamuras T-Engine Hardware and a complementary operating system, the Tron House 1, 2 and 3 have been built 1. The US AwareHome 5 and PlaceLab 6 follow a similar approach and MIT’s House_n 7 includes even modular intelligent furniture that can be equipped with various sensor systems. Recently designed German prototypes of assistive homes, such as “Haus der Gegenwart” (house of presence) 8 and “Haus der Zukunft” (house of the future) 9, are exemplarily equipped with a variety of networked pervasive technologies integrated by modern design. Similar to our approach Smart Buildings and Robotic Rooms
try to integrate sensor-actuator systems with architectonic elements. Smart Buildings can make these systems quite invisible but their performance is limited to more “passive” services that support cognition, energy control, logistics, safety and security.

Activities of Daily Living (ADLs)\(^{10}\), which represent tasks in everyday living people need to be able to manage as independent adults, are in most cases not considered or supported by smart buildings realizations. Robotic Rooms\(^{11}\) on the other hand can cover the support of more physical activities through robotic systems. However, service robots and mobile robotic platforms are visible, and some sub-systems can be recognized by the supported person as robots. Approaches in the area of Ambient Assisted Living (AAL) mainly focus on health monitoring and patient-physician related communication. Thus, the integration of Digital Communication Frameworks within the home environment comprises an active subject of many ongoing research projects, whereas the integration of Robotic Systems into the home environment is completely neglected.

Furthermore, AAL is mainly driven by the Informatics and Electronics industries without a focus on real architectonic integration. Most projects in that area work with add-on solutions as for example wearable sensors and set-top boxes that have no relation to room configurations or functional layouts. The proposed approach combines elements of Smart Buildings, Robotic Rooms and AAL technologies. However, unlike Robotic Room approaches, this one deals with fully integrating distributed robotic systems with subsystems of buildings, enabling the passive services as well as the hard physical services through mechatronic systems and robotics, to become invisible. In most cases this requires an understanding of living processes, the design of the environment and the design of embedded systems.

Research Question and Method

Buildings and environments consist of a multitude of subsystems as for example walls, ceilings, furniture, service cores and many others. In order to realize the proposed vision of seamless robotic assistance, since 2008, subsystems were investigated in order to obtain insights on how they could be efficiently integrated with mechatronic and robotic elements. This was performed by an interdisciplinary team of researches with backgrounds in architecture, design, electrical engineering, mechanical engineering, informatics and health related sciences. Currently the research team enters Step 3. In this paper building subsystems that have been integrated with mechatronic and robotic elements during step 1 are presented. In the following sections the basic concepts are described in order to explain which show potential for delivering extended services, especially for the ageing society, through this integration. Additionally the core technologies are outlined as well as the design concepts which were utilized to facilitate integration. Finally, it is shown that the ultimate goal is to connect these robotic subsystems to a totally integrated robotic environment (Table 1).

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>Wall</th>
<th>Ceiling</th>
<th>Service Core</th>
<th>Cabinet</th>
<th>Seat</th>
<th>In-House Mobility</th>
<th>Bathroom</th>
<th>Combined In-/Outdoor Mobility</th>
<th>Integrated Robotic Environment</th>
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<tbody>
<tr>
<td>Project</td>
<td>Robotic Service Wall–Research Project LISA</td>
<td>Modular Ceiling Robot</td>
<td>Robotic Service Core</td>
<td>Robotic Cabinets</td>
<td>Robotic Chair - Research Project GEWOS</td>
<td>Robotic In-House Transfer</td>
<td>Automated Bathroom</td>
<td>Research Project: PASSAge</td>
<td>AIR LAB</td>
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<tr>
<td>Phase</td>
<td>Step 1: 2008-2011</td>
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EXPERIMENTAL APPROACHES ACCORDING TO CATEGORY

In this section the proposed experimental approaches are presented and the potentials for delivering extended services are outlined. The conducted experiments are categorized into Table 2. Eight different applications are addressed, aiming in providing assistance in the home environment, especially focused in elderly people situations. Frail older people face numerous challenges in performing ADLs. Simple tasks for a healthy individual are projected under a different perspective to elderly people. Usually, according to the physical condition of the individual, they require the assistance of an extra person in order to perform basic tasks, such as
bathing, eating, dressing undressing etc. This decreases the independence of elderly people. The proposed research focuses on service delivery, by the integration of robotic elements, mechatronic devices and technologies, which would increase the independence of elderly people in performing basic ADLs. Such assistive technologies could thus greatly enhance the quality of living.

Table 2. Overview own experimental approaches according to categories

<table>
<thead>
<tr>
<th>Robotic Service Wall</th>
<th>Modular Ceiling Robot Concept</th>
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</thead>
<tbody>
<tr>
<td>Robotic Chair</td>
<td>Robotic In-House Transfer</td>
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<tr>
<td>Robotic Service Core</td>
<td>Robotic Cabinets</td>
</tr>
<tr>
<td>Automated Bathroom</td>
<td>Combined Indoor-Outdoor Mobility</td>
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</table>

**Robotic Service Wall**
The Robotic Service Wall is implemented under a two year funded research project called LISA "Living Independently In South Tyrol Alto Adige" (July 2010-July 2012). The consortium consists mainly of industry partners with Technical University of Munich as center point of the consortium both in terms of strategy and technology development. In LISA, the implementation of a novel Robotic Service Wall supporting ADLs is the main objective. The proposed system followed a modular approach, whereas all system elements provide “plug and play” characteristics. Robotic actuators, sensors and display screens are populating the proposed robotic wall, in order to enable an Ambient Assisted Living approach. The user can voice command the robotic wall in order to initiate a service or to acquire information on the provided services. The proposed system can be arranged and re-arranged into various configurations, and can be easily installed in any residence without requiring specific space dimensions.

**Modular Ceiling Robot Concept**
The purpose was to develop, by a combination of architectural and robotic elements, a system that assists elderly people to live self-sufficient at home. Unlike many other assistance systems our system exploits the ceiling space in order to avoid collisions with conventional living functions. A ceiling suspended robotic system is proposed, navigating with the aid of a grid type rail system among various rooms within a residence. This enables efficient space utilization since it occupies the redundant area of the ceiling. Various types of services can be provided by the proposed system such as health monitoring, infotainment, communications, problem solving, movement assistance, etc.

**Robotic Chair**
The implementation of the robotic chair is supported by a funded R&D-project in the field Ambient Assisted Living called GEWOS. The main objective was to develop a chair that is equipped with invisible but sophisticated sensor technology that measures a multitude of user’s vital signs. This inconspicuously and at first glance invisibly integrated sensor modules form the basis for professional activity and sports concepts, health assistance, business and service concepts that are delivered as “services” through the chair and its interface as channel to the users, which through the sensor systems actually becomes part of the system. Therefore GEWOS considers the sensor chair as a socio-technical system, comprising an internet-based platform, an interface component, and further interaction elements and matching services. By encouraging movement and supporting further constitutional methods, this system serves as a health promoter, embedded in the physical and emotional surrounding of the user.

**Robotic In-House Transfer**
The proposed approach dealt with identifying the needs and requirements elderly people face in performing ADLs, by conducting a survey among various age groups and identifying the main bottlenecks...
and limitations. A design procedure was then proposed in order to provide an efficient solution in optimizing the independence in functional transfers (getting into and out of bed or wheelchair, getting onto or off toilet, etc.) of elderly people within the home environment. The proposed concept comprises the combination of robotic and architectural elements, aiming at the realization of a novel indoor mobility device enabling independent living, efficiently addressing the mobility difficulties elderly people face within the home environment.

**Robotic Service Core**
The prefabricated Service Core is a unit which could be integrated into apartments as a "room within a room" system (Fig. 06??). With its standardized height of 235cm, it could be positioned in an apartment in an old building as well as in a newly built house. Similar to prefabricated bath or toilet-units for high rise buildings, which have been used in building industry since the 1970s, the service core could be delivered to the site as a prefabricated kit. The Service Core is designed for people with severe disabilities and cognitive diseases. The service core offers most functionalities and appliances which are needed to serve severely handicapped persons who remain indoors. Minimum movement is required to perform daily tasks, since bath and kitchen can be directly and ergonomically reached from the bed area, which can be transformed into a seat. Within the service unit, the health condition of the handicapped person is continuously measured and digital cameras allow relatives, physicians or service personnel to observe the patient and check the current condition in real-time or in regular time intervals. For health monitoring various sensor-based devices are installed in the service core. Additionally the ability of relatives or a physician to communicate with the individual is provided via an integrated communication screen interfaced via internet. The service room can be considered as a very compact hospital or care facility deployed at home. Its aim is to provide severe disabled individuals the possibility to remain as long as possible at their home environment, through the fusion of functional architecture, embedded microcontrollers and ambient intelligence technologies, within an enhanced performance compact and modular service unit. An implemented smaller scale prototype was realized and implemented for evaluating and testing the overall concept (Table 2).

**Robotic Cabinets**
Ergonomics is the engineering science that is concerned with the physical and psychological relationship between machines and the people who use them. Furniture is designed to adapt to specific needs, supporting various human activities. According to the application, a set of guidelines or rules is followed during design, in order to provide ergonomic features. The proposed robotic cabinet system provides an integrated solution, comprising reduced space utilization, modularity, and intelligent operation while remaining an ergonomic piece of furniture. A set of electrical motors is used to position the various sections of the system into the correct height level, and to displace them towards the horizontal axis, to allow a rotational motion path. The implemented prototype was evaluated in terms of, ergonomics (using an age simulation suite), organizational ergonomics within a room, and space utilization (as the individual sections/shelves can rotate in a vertical direction, the proposed system is possible to be installed in small rooms, achieving a 20% less space utilization usage, in order to allow free space for mobility with rollators or wheelchairs).

**Automated Bathroom**
An approach towards robotic hygienic assisted services focusing in the global demographic change problem is addressed by the proposed research. The proposed approach dealt with identifying the needs and requirements by conducting a survey among various age groups and identifying the main bottlenecks and limitations. A design procedure was then proposed in order to provide an efficient solution in optimizing hygienic services in the home environment while increasing the independence of elderly people in the corresponding ADLs. The proposed concept comprises the combination of robotic and architectural elements, aiming at the realization of a novel robotic bathroom which can automate the bathing procedure.

**Combined Indoor-Outdoor Mobility**
The implementation is supported by a funded R&D-project in the field Ambient Assisted Living called PASSAge. The PASSAge addresses the mobility issues within an ageing society by developing a modular and personalized mobility system, that can be integrated into the individual surrounding of the user and encourages individual mobility as well as supports safety, comfort and health, and therefore enhances quality of living. Adaptable, customizable and user-friendly add-on modules (operation and shopping help, health phones, transfer support at the entrance of buildings or within buildings) are being adapted from existing technologies and innovative mobility components in the field of personal mobility devices.

**CORE TECHNOLOGIES**
**Using ROS/GAZEBO as Middleware**
Building Information Modeling is one of the recent developments in architecture, construction and engineering which helps to visualize, support and manage buildings during design construction and opera-
tion. The developments in the field of pervasive computing though made the buildings more complex making the current Building Information Modeling (BIM) tools obsolete, as they do not contain functionality to integrate sensor data and other pervasive technologies. Also in a pervasive environment there is a need for the building model to interact with the surroundings in real-time. Mahdavi’s research on sentient buildings illustrates that for a building to be intelligent and proactive, the building model should be able to read inputs from a wide array of sensory networks, and update itself on real-time. Thus, the requirement to access and control the various sensors and computers in a ubiquitous environment introduces the need for a middleware.

Robot Operating System (ROS) is one such middleware, able to enable control over the various sensors and exchange data information in real-time. ROS can be used along with a 3-D visualization simulator environment called Gazebo to create a model for a ubiquitous environment. Modeling in Gazebo is done by considering the building as an immobile robot with various joints and links. Creating a model using the concept of joints and links enables the building model to be more dynamic and updated in real time based on the sensor information. With proper mechatronic systems this also gives the option to control the dynamic parts of the building from a remote location. Also this ROS/Gazebo integration is more suited to an environment cohabited with robots as shown in Figure 1 where these tools simplify the complexity required for the robot in order to successfully navigate the architectural space and perform the required tasks.

RFID Technology
In recent years, radio frequency identification technology (RFID) has moved from insignificance into conventional applications that aid in simplifying the handling of items and objects. RFID enables identification from a distance, and unlike earlier bar-code technology, it functions without requiring a line of sight or a specific visual pattern to be detected, recorded and processed. RFID tags (see Figure 2) support a larger set of unique IDs than bar codes and can incorporate additional data such as manufacturer, product type, and even measure environmental factors such as temperature. Furthermore, RFID systems can discern many different tags located in the same general area without human assistance. In contrast, consider a supermarket checkout counter, where the personnel must orient each bar-coded item towards a laser scanner reader in order to identify it. If all items had an RFID tag attached on them, the checkout process on the counter could have been fully automated without explicitly requiring human assistance.

Many types of RFID exist, but at the highest level, we can divide RFID devices into two broad classes: active and passive. Active tags require a power source, i.e. they are either connected to a powered infrastructure or use energy stored in an integrated battery. One example of an active tag is the transponder attached to an aircraft that identifies its national origin. However, batteries make the cost, size, and lifetime of active tags impractical for most small scale applications. Passive RFID tags are thus preferred because they don’t require an external supply source. The tags also have huge operational lifetime and are tiny enough to fit into a practical adhesive label.

A passive tag consists of three parts: an antenna, a processing unit attached to the antenna, and some form of encapsulation. A tag reader is responsible for powering and communicating with a tag, which is attached either to a personal computer or to a digital communication network. The tag antenna captures energy and transfers the tag’s ID. The tag’s processing unit is responsible for coordinating the communication and transmission process. The encapsulation maintains the tag integrity and protects the antenna and processing unit from environmental conditions or damage.

![RFID tags](image2.jpg)

**Fig.1. Robotic environment modeled in Gazebo using concept of links and Joints**

**Fig.2. RFID tags**
In a home environment this technology can be utilized to assist elderly people by providing them a real-time inventory of their high priority items. Experiments conducted during the proposed study, revealed the efficiency of this "invisible" technology, and the variety of potential applications that this technology can contribute to. By combining computerized databases and inventory control, linked through digital communication networks spread across the home environment and across a global set of locations, RFID technology can efficiently pinpoint individual items as they move between locations, warehouses, vehicles, and stores.

Vision Systems
Depth perception is one of the important tasks of a machine vision system. Stereo correspondence by calculating the distance of various points in a scene relative to the position of a camera allows the performance of complex tasks, such as depth measurements and environment reconstruction. The most common approach for extracting depth information from intensity images is by means of a stereo camera setup. The point-by-point matching between the two images from the stereo setup derives the depth images, or the so called disparity maps. Disparity map extraction of an image is a computationally demanding task. Due to the computational complexity involved in stereo vision algorithms, powerful CPUs are required to achieve acceptable performance. Recent research has shown that such low level image processing algorithms can be efficiently implemented in hardware.

The proposed research deals with implementing depth extraction algorithms using stereo camera arrangements or depth sensors, like the "Microsoft Kinect" Sensor. The acquired depth representation of an individual on a chair within the laboratory environment using Microsoft's Kinect depth sensor is depicted in Figure 3. The depth map was acquired using a Turtlebot mobile rover, which an onboard Microsoft depth sensor. The mobile rover can be seen in Figure 4.

Depth perception allows the autonomous navigation of mobile robots, object recognition and people detection. These implementations aim to integrate an efficient vision system in the home environment, in order to allow systems to be operated by people gestures or movements. Additionally the presence of a person within different areas of an apartment can accordingly trigger the deployment of robotic elements and mechatronic devices, in order to allow an Ambient Intelligence environment realization.

CONCLUSIONS AND FUTURE WORK
New application fields for robotics in the area of service and environmental assistance are generated through the tension between market pull on the one hand and technology push on the other. However, the integration of robotic systems and sub-systems is likely to transform the appearance of our environment and everyday artifacts similar as done through the implementation of new materials or technologies before.

The integration and permeation of our environments and social spaces with robotic technology and related sub-systems will lead to new concepts and explore new forms as robotic walls, robotic furniture, robotic care environments, mobility robots and robotiic everyday companions. Obviously emerging technologies are not only transforming functionality of upcoming hybrid robot-environment systems but also designs and forms of our environment following the principle of "form follows function" (Sullivan, 1896) being discovered and scientifically explained by L. Sullivan more than one hundred years ago. Despite all complex interdependencies and transformations, underlying principles as modularity, customization capability, system distribution, standardization and a well defined human-robot relation seem to be helpful tools in designing future hybrid robot-environment systems. Above that, modularity and standardization are important prerequisites for industrially fabricated and customized robotic enhanced
assistive environments. Complex and multilevel high-tech environments will only reach affordability and long-term serviceability when fabricated with frontier industrial technology. Furthermore, tools like ROS and Gazebo have become more important in light of new building concepts with embedded robotic systems. Over centuries buildings have always been viewed as static structures resistant to changes. However, more recently there have been a different viewpoint about buildings, and they are often viewed as kinetic structures capable of changing its structure or profile to suit the various environmental or user conditions. The concept of kinetic architecture or dynamic buildings is currently being exploited by many architects around the globe. Some projects use these concepts to make the building more sustainable and intelligent while other projects employ these concepts for assistance. We use embedded robotics to build up robotic service environments that are completely integrated in our environment to support activities of daily living. Currently a modular, 1:1 scale robotic testing flat is finalized for experimenting at the author’s robotic laboratory, Figure 5. In this environment the aforementioned systems shall be integrated to a total robotic environment.

The proposed research is not focusing on integrating mainly sensors, actuators and robots on an informational level, nor oriented to implementations that are realized in a controlled experimental environment. The proposed research targets robotic service delivery straightforwardly applied into regular home environments. In order to integrate those services on basis of technologies seamlessly and connect them to ADLs\textsuperscript{10}, a fusion scheme of robotic technology physically and informational with architectural elements as e.g. walls and barrier-free design is proposed. The advantage of such an approach is that that existing walls do not have to be replaced. Analysis showed that a smart wall which would replace existing walls would become too complex and too expensive to install. In order to keep cost and effort low enough for equipping a flat with smart technology, it was proposed to concentrate assistive technology on terminals instead of developing a smart wall. Each terminal can be deployed in front of an existing wall as a pre-fabricated kit. A terminal concentrates assistive functions and technologies that have to be brought into a room on a compact element. Thus, in case a room has to be equipped with assistive technology, not the whole room has to be rearranged or renovated, but only one of the proposed compact elements has to be installed in this room as an add-on.

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A Multi Robotic Assistant System (MRAS): A development approach with application to the ageing society

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Purpose Our purpose was to develop, by combining architectural and robotic elements, a system that assists elderly people to live self-sufficiently at home. Unlike many other assistance systems our system exploits the ceiling space in order to avoid collisions with conventional living functions. Method Elderly people face numerous limitations in their everyday life. The simplest regular tasks a healthy individual performs appear quite different from the perspective of the ageing adult. Healthcare and mobility usually appear as distant services in cases of isolated individuals or lack of transportation due to disability. This paper deals with the development of a novel multi-robot assistant system (MARS), which can be used to provide indoor quality services to the ageing society. In order to realize the MARS concept the following development approach was used: (i) research and identification of needs; (ii) definition of requirements; (iii) identification of technologies and processes; (iv) initial concept; (v) experiments in real environment; and (vi) final concept and further development roadmap. Results & Discussion A ceiling suspended robotic system is proposed, navigating with the aid of a grid-type rail system among various rooms within a residence. This enables efficient space utilization since it occupies the redundant area of the ceiling. Various types of services can be provided by the proposed system such as health monitoring, infotainment, communications, problem solving, movement assistance, etc. A vision system aids in obtaining accurate information on the location of the individual within the residence, and in guiding the whole system during the operation of the required tasks. A series of experiments were conducted in order to define the proposed system specifications. Verification experiments in a real residence with three different individuals were performed, in order to calculate the forces applied to the human body while sitting and standing up (Figure 1). This type of movement is the most awkward and laborious for elderly people. MRAS can assist elderly people by using a flexible pulling wire which can be easily either grabbed by the user or fastened onto.

Keywords: ambient integrated robotics, architecture, multimorbidity, stereo vision

INTRODUCTION Demographic change studies, dealing with elderly population growth, reveal a relatively rapid increase, and it is expected that in the next half century the proportion of elderly people will increase from 7% in 2000 to 16% in 2050. The majority of the elderly people face health problems that oblige them to remain at home and to depend on another person. Hence, it is essential to focus on the elderly people needs and work on robotic devices that will provide them an independent and dignified everyday living. Research community has focused towards this direction and has been presented assistive devices that aim to facilitate the daily activities of elderly people, such as for example: PPMA system for personal mobility aid and health monitoring4, robotic walker for navigation and obstacle avoidance5, MAT robot for domestic activities (housekeeping, eating, grooming, entertainment, etc.)6. Several ceiling suspended lift systems for elderly and disabled people are currently on the market7. All of these systems impose several limitations, since they are restricted to specific path ways, are expensive and require major modification within a flat. Additionally, they can only be used for one purpose: the purpose of lifting persons. Furthermore, several researchers are working on mobile and dexterous service robots that operate on the ground8. Those systems often can assist with multiple tasks but their area of operation is restricted as they are bound to the ground and complex interactions with human beings and other obstacles as furniture are unavoidable. The ceiling can be identified a perfect space within any environment for the guided and efficient operation of a service robot. The concept of a ceiling robot within an environment has already been explored by Sato9.

In this paper a combination of existing approaches is proposed, leading to a novel multi robot assistant system (MRAS). The system aim is to assist in Activities of Daily Living (ADLs)10, and is especially oriented to the needs of the aging society. The system has the ability to move in all rooms of the residence without occupying floor space, since it moves on the ceiling using a rail type grid system. The system is multifunctional accomplishing various activities (e.g. health monitoring, delivering prescribed medication at appropriate times and dosages, info-
tainment, communications, etc.). Moreover, the system provides the ability to aid the elderly people in functional transfers, i.e., move from a sitting position to a standing position.

**MRAS Concept and Its Main Features**

MRAS concept presents a multi robot assistant system based on the ergonomics concept, since it utilizes the ceiling area which is unexploited. Thus, it does not occupy area of the floor, allowing elderly people to easily move within a residence, especially when considering people using mobility assistive devices such as wheelchair and rollators. Additionally, it can be customized, in terms of functionality, in order to adapt to the exact needs of each user, since the weaknesses and health problems of each user differ.

One common problem that elderly people have to face is the accidents in the residence especially due to falls. In order to aid elderly people with eye disorders, the robot system is able to automatically adjust the lightning conditions within a residence, depending on the time of day and the degree of darkness in the room.

The MRAS also incorporates an air purifier that reduces the air contaminants, improving the quality of living of people with respiratory problems. In addition, this system in combination with the lightning control system can provide the adequate environment for sleep, since the majority of the elderly society faces sleep disorders.

Moreover, the MRAS integrates a medication dispenser. The system dispenses medication to the individuals at corresponding time intervals and in the appropriate dosage. In this way, the individuals receive medication in a proper manner, avoiding mistakes and without missing out doses. Moreover, a measuring system monitors the individual’s vital signs, through measuring blood pressure and blood glucose levels at daily intervals. The obtained data are compared to the allowed limit values. In case that the measured values overcome the allowed limit values, an emergency signal is transmitted to a registered physician. The weekly values are also transmitted to a physician in order to be informed about the individual’s weekly health status.

MRAS can also assist elderly people in their functional transfers, by using a flexible pulling wire which can be easily either grabbed by the individual or fastened onto them using a wearable harness. More specifically, the system can move the elderly people from a sitting position to a standing position or from a lying position to a sitting or standing one. The value and the direction of the force that must be applied to pull the individual by the wire in order to change his/her position is achieved by the calculation of the external force in each position step as shown in Figure 1. Experiments with three different individuals which move from sitting position to standing position were performed, in order to estimate the required forces applied, and define the necessary payload of the system. The movement has been separated in 5 “sub-movements” as shown in Figure 1.

![Fig.1. Experiment for calculating the amount of forces individuals are subjected to, during functional transfers](image)

**MECHANICAL CONCEPT**

The mechanical concept of the proposed MRAS was defined after considering the following terms:

- Technology,
- Modularity,
- In-Exchangeability,
- Low Maintenance.

Next Generation robotics could help ease the partially intricate life of the elderly. The addition of features and availability would result in a reduced need for
caretakers, and raise the independence of elderly people, in order to be able to perform easily the ADLs and remain more at their homes. With a wide spectrum of exchangeable robotic elements, such as manipulators and actuators, a more individual robotic system is feasible. Each person has different needs, and thus a robotic system could be adjusted to fit explicit needs.

By following a modular structure, the robotic system would not only be more cost efficient but also give the possibility of enhanced service delivery. These features could be updated and exchanged upon request, offering the possibility of an increased diversity through third party development. The use of a modular system also introduces an adaptive concept and lessens the chance of cost ineffective and complex component exchanges.

Equipped with Plug-n-Play functionality, the proposed MRAS would be able to have almost infinite feature availability through third party developers. Ease of component exchange and installation, also reduces installation errors. The idea is to keep the robotic system as flexible as possible without loss of performance.

A system needs to require low maintenance in order to be considered efficient. This not only reduces expenses but also overcomes possible hassle between the customer using the system and the manufacturer companies that cover its warranty. A low maintenance health care system can be in the future provided to the elderly by the healthcare provider sector, if the required procedure involves only mounting, i.e. a plug-n-play behavior.

**DESIGN APPROACH**

The MRAS design followed the aforementioned considerations in order to comply with the required specifications, and enable a system that will efficiently address the ageing society needs. A system overview is provided in Figure 2.

The proposed system is divided into 3 main components:

- The Main Grid (Rectangular Arrangement Grid)
- The Main Actuator (Basic Component)
- The Main Body (Ex/-Interchangeable)

**Main Grid**

The main grid comprises a rail type grid infrastructure attached to the ceiling, which provides the means for mobility within the various areas of the residence. According to the final dimensions of all system modules, an appropriate grid structure is attached to the ceiling, consisting of rectilinear steel rails, arranged in a rectangular mesh, in order to allow the robotic system to be able to move nearly to all possible locations within each operating area.

**Main Actuator**

The main actuator comprises the mobility element of the overall system. It is responsible for directing the structure to the correct location, utilizing the steel rail grid attached to the ceiling. The main actuator is the central core of the MRAS. The actuator itself uses spherical rubber and steel wheels to navigate the grid. The form and buildup of the wheels allows a directional navigation in both Y and X direction. The software algorithm used to navigate the grid could be
based on the Cartesian system. The information exchange to and from the main actuator is transmitted by wireless LAN. A charging station located at a predefined position of the grid, allows the internal Li-ION battery of the main actuator to be charged, while it is docked at the charging point. The internal battery is used as a backup alternative power supply mode, in cases of power failures and blackouts. While operating in normal power mode, the main actuator is supplied by the rail grid structure, which is interfaced to the main power supply of the apartment.

In order for the main actuator to be able to progress through the rectangular arranged grid, a sort of guiding mechanism needs to be implemented. At all intersection points of the rectilinear rails, a ball bearing arrangement was designed in order to successfully guide the main actuator module into the required directions, Figure 3. Once the main actuator wheels are positioned within the intersection points, the ball bearing arrangements rotate them by 90 degrees in order to align them with the perpendicular rail. Thus, the redirection of the main actuator to a perpendicular rail is achieved.

![Fig.3. Rail guiding system](image)

**Main Body**

The main body component comprises the end-effector module of the overall robotic element. It serves as the service delivery module, since it provides all the functionality and service delivery to the user. It is attached to the main actuator component via a telescope rotator unit, enabling rotation to all possible directions, allowing a 2-degrees-of-freedom operation.

The main body component follows a modular and customizable design, in terms of functionality and service delivery. The proposed concept focuses on enabling a fully modular and customized robotic system, in order to comply with low maintenance requirements, such as easy to upgrade and repair in case of malfunction. The design of the main body is depicted in Figure 4. A miniPC located under the rear cover, serves as the processing unit, handling all required processes and operations, as well as deploying the modular units of the proposed component.

![Fig.4. Main Body Component](image)

**PROPOSED FUNCTIONALITY**

The functionality and features of the proposed MRAS focus on providing services assisting elderly people in daily activities within the home environment. Additionally, since the MRAS concept aims to increase the independence of elderly people and allow them to spend more time in their home environments, a series of applications and services contributing towards this goal, are proposed.

**Direct Light**

Direct lighting can be offered in areas of the home environment that low lightning conditions are detected, regulated by the main control module. Light regulation, can be performed not only according to brightness but also to color, depending on the time of day and the degree of darkness in the room. Deployable panels populated with an LED mesh can offer direct light according to the user requirement. Additionally the control unit can adjust the panel angle and direction to achieve optimum lighting conditions.

![Fig.5. Direct Light Configuration](image)

**Noise cancelling**

Through the use of ANC (Active noise control) and anti-phasing technology, repetitive noise patterns can be reduced or even “cancelled”, leading to a more quite environment. The speaker unit attached to the main body module shown in Figure 5, can be used, controlled by a Digital Signal Processing (DSP) algorithm, to emit “Anti-Noise” signals to reduce or even cancel out city urban noises such as traffic, horns, alarm sirens, etc. The graphical depiction of Active Noise Reduction is shown in Figure 6.
Passive Healthcare

The goal is the establishment of DIY (do it yourself) healthcare system. Depending on the technological progress, a microwave/laser emitter and receiver unit can be attached to the front part of the main robot. A passive measurement on the user blood pressure could be performed. The acquired measurement data can be exchanged via a digital communication network to a physician to allow tele-care and tele-consulting.

Additionally a needless injection feature was concerned. Many elderly people require daily injections which are performed by designated health care personnel. A system can be attached as an add-on to MRAS in order to perform injections without requiring the presence of a specialized person. The technology preferred would be a solid micro-needle system that attaches to the skin and slowly injects the required medicine, which could be air-gunned from the main body component to the patient.

A medication dispenser mechanism was also considered as one of the offered services of the proposed concept. A medication cartridge unit, which can be filled at a pharmacy, facilitates the medication dispenser module. The cartridge can consist of several chambers, to allow various medications to be stored. A small robotic component travelling along a rail automatically collects the according medicine from the chambers and dispenses it through an opening into a small plastic package. Once the appropriate type and quantity of medication has been collected and placed into the small plastic bag, the package is then dropped onto an area determined by the patient.

Assistance in functional transfers

The main body component can be configured to assist elderly people in their functional transfers (moving from a sitting position to a standing position or from a lying position to a sitting or standing one), by using a flexible pulling wire which can be easily either grabbed by the individual or fastened on them using a wearable harness. The proposed designed configuration can be seen in Figure 8.

A wearable harness can be used in combination with the proposed configuration to assist individuals to perform functional transfers easier. A deployable wire can be lowered to the individual level, in order to be secured to the harness mechanism. Once secured firmly, a pulling mechanism retracting the wire can allow functional transfers to be performed in a more comfortable and supervised manner.

Human-Machine Interaction Scheme

The operation of the proposed MRAS concept and the service delivery can be controlled by a stereo vision camera system attached to the front of the main body component. The target person must be
able to be detected by the robotic system in real-time, in order to allow efficient seamless and autonomous operation.

Depth perception is one of the important tasks of a computer vision system. Stereo correspondence by calculating the distance of various points in a scene relative to the position of a camera allows the performance of complex tasks, such as depth measurements and environment reconstruction. The stereo correspondence problem comprises an active wide range of research. Many efforts have been made towards efficient solutions to address the various issues of stereo matching. As the improvements in computational resources steadily increase, the demand for real-time applications is getting compulsory. The most common approach for extracting depth information from intensity images is by means of a stereo camera setup. The point-by-point matching between the two images from the stereo setup derives the depth images, or the so-called disparity maps. A stereo camera setup interfaced at the front of the main body component, can offer people detection, object recognition and many more.

A combined voice recognition module can increase the performance of the MRAS response capability. Vocal messages issued by the user, can be interpreted into commands to initiate services or to define required operating modes. Moreover, user queries regarding health status information, or lighting regulation, or even infotainment services can be used to control various functions and services. A human-computer interaction scheme can thus be implemented.

**CONCLUSIONS**

A novel Multi Robotic Assistant System (MRAS) concept is proposed, focusing in assisting ageing society individuals within the home environment. The proposed system specifications were defined considering the need for a system realization that would comprise unattended health care services delivery, low maintenance costs, unobtrusive customization via modular add-ons provided by third party developers, autonomous operation, and human-machine communication features.

Verification experiments in a real residence comprising three different individuals were performed, in order to calculate the forces applied to the human body while performing functional transfers. These types of movements are the most uneasy and laborious for elderly people. MRAS can assist elderly people by using a flexible pulling wire which can be easily either grabbed by the individual or fastened onto. Elderly people usually utilize assistive devices such as wheelchairs and rollators. The requirement for enhanced space in order to freely move around their home environment is evident. MRAS concept efficiently addresses this issue, since it utilizes the unoccupied space of the ceiling. A rail type grid, to which the rest of the system is attached onto, is used in order to provide the necessary navigation paths within the operating area.

A stereo vision system along with a voice recognition algorithm is proposed to provide a human machine interaction scheme. Vision-based perception of moving people comprises one of the active research fields in computer vision. Monitoring people movements in complex environments, analyzing the resulting motion patterns and understanding people gestures corresponds to a high level of visual competence that can most appropriately be identified as Ambient Intelligence (AmI).

The proposed MRAS concept aims in providing a user-centric paradigm, supporting a variety of ageing society related daily living issues, operating pervasively, nonintrusive, and transparently.

**References**


Assessing design features of a graphical user interface for a social assistive robot for older adults with cognitive impairment

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Purpose

Over the past several years, a variety of assistive technologies have been conceived and developed to support independent living and quality of life of older adults with mild cognitive impairment (MCI) or Alzheimer's disease (AD). Within this area socially-assistive robotics is a growing field. However, although robotics has the potential to support the elderly with cognitive impairment in daily tasks, the development of usable interfaces remains a challenge. For instance, changes in perceptual and cognitive abilities should be addressed in robotics design because they affect technology use. The aim of the QuoVADis project was to develop a socially-assistive robot for elderly people with cognitive impairment. The semi-autonomous remotely controlled robot consists of a mobile platform guided by a computer and electronic system. The robot input devices include speech control and a touch-screen. The system, capable of social interaction, was specifically conceived to provide cognitive and social support to the user through a suite of applications (task reminder, cognitive training, navigation support, and communication). The purpose of this work was to develop the graphical user interface (GUI) through which these services are provided. In a previous study we defined a set of requirements that were used to design the robot's GUI. In this paper we present results from usability testing of the functional prototype of the GUI with target end-users and the modifications made to produce the final version of the applications.

Method

We used a user-centred design approach for the GUI design. Eleven elderly persons with MCI and 11 elderly with normal cognition were recruited for this study. First, the moderator described the purpose of the research, introduced the robot and explained the evaluation procedure. Then participants were asked to complete a series of tasks using the main menu of the GUI and navigate through its different applications. Performance and satisfaction measures were collected (e.g., time to complete each task, number of errors due to manipulation, number of help requests). Tests were conducted individually.

Results & Discussion

Findings confirmed that most of the features of the GUI were adapted to the needs and capacities of older adults with cognitive impairment. However, individual factors (age, education level, and computer experience) were found to affect task performances. Moreover, some particular aspects of the interfaces (icons, navigation system) had to be modified to make the application usable by the largest number of patients suffering from cognitive deficits. These results were used to develop the final version of the GUI. We confirmed that designing and developing assistive technologies to support elderly with cognitive impairment requires end-user involvement throughout all the development and evaluation phases. This study is an example of a successful design process for assistive technologies to support MCI-patients and their caregivers, involving them throughout all the development phases and applying the concept of iterative evaluations.

Keywords: socially assistive robotics, elderly, cognitive impairment, graphical user interface

INTRODUCTION

Mild Cognitive Impairment (MCI) is a condition that affects approximately 10% to 20% of people aged over 65 years 1. MCI is usually characterized by memory loss but other cognitive deficits can be involved. Although individuals with MCI maintain functional independence in daily life they can exhibit some difficulties when performing complex tasks (e.g., managing bills, preparing meals, medication intake). Besides, studies indicate that these persons are at higher risk than their healthy peers of developing Alzheimer’s disease or any other form of dementia. Accordingly, individuals with MCI that progress and convert to dementia have an increasing need of formal and informal care.

Information and Communication Technology (ICT) has been used to develop solutions to support frail older adults and caregivers in their home 2. These solutions include sensor technology, telecommunications, safety alarms, monitoring devices, cognitive prosthesis, mobility aids, and robotic systems, among others 3,4. Responding to the needs of these populations has become a major aim of Socially Assistive Robotics...
(SAR)\textsuperscript{5}. SAR concerns robotic systems capable of providing assistance to the user by means of social interaction\textsuperscript{5}. Their scope covers a wide range of tasks for which assistance can be provided without physical interaction. In general, SAR have the potential to contribute to user’s daily life at different levels\textsuperscript{1,8}:

(i) By supporting and/or compensating functional abilities of the person through different technology-based services (e.g., task reminder, task monitoring, schedule-management systems, navigation aids).

(ii) By contributing to social and psychological well-being of end-users (e.g., communication and social networking services, companionship aspects, recognition and expression of emotional states, collaboration and engagement capacities).

(iii) By providing monitoring that contributes to healthcare and safety. With regard to this issue, SAR can be associated with other devices capable of collecting data on the physiological activity of the person (e.g. fall detector).

(iv) By making a continual assessment of the user’s cognitive functioning through the analysis of daily behavior. This aspect concerns applications that collect performance measures during task execution and facilitate the follow-up of cognitive deficits.

User-system interactions

Different modalities can be employed to ensure the interaction between social robots and users\textsuperscript{6}. Individual interaction modalities include speech (voice user interfaces), gestural interfaces, and direct input (e.g., touch-screen interface). Furthermore, multimodality constitutes an alternative interaction solution in which individual modalities are combined.

The QuoVADis project

The aim of the French project QuoVADis\textsuperscript{9} (2008-2011) was to design and develop a social robot for frail elderly people with age-related cognitive impairment or with a diagnosis of MCI. End-users could also present one or more of the following conditions:

(i) Chronic illness requiring medical follow-up.

(ii) Risk of falling.

(iii) Risk of social isolation or exclusion.

The project was structured into a number of working tasks in which we defined, developed and evaluated a set of services that a robot could provide to support care recipients, as well as family caregivers, in daily activities. Working tasks included: user needs assessment, requirements gathering, prototype development and iterative usability evaluations with functional prototypes of the robot and its applications.

The Kompaï robot

Kompaï (Fig. 1) is a mobile platform guided by a computer system developed by Robosoft\textsuperscript{10}. A Web browser or a joystick can be used to remotely control the robot. The robot embeds a group of sensors and cameras that ensure robot’s autonomous navigation, target user localization and obstacle detection. Input devices include speech control and a touch-screen from a Tablet PC running Windows 7.

Within the QuoVADis project, the system was specifically programmed to provide cognitive and social support through a suite of applications (e.g., task reminder, cognitive training, navigation support, communication tools). In the present study we focused on the design of some graphical navigation elements of the Graphical User Interface (GUI) since the direct input device (touch-screen) was one of the interaction modalities defined for the robot.

Fig. 1. Kompaï Robot (Robosoft)

Robot GUI

GUI based-systems generally consist of a visual display that uses graphical elements (icons, buttons, menus), rather than only text, to convey information and allow navigation in a computer application. Robot GUI was developed using a User-Centred Design (UCD) approach. An incremental development process was followed to investigate each design feature and to implement it progressively in the general prototype\textsuperscript{11}. With this aim, formative usability tests with end-users were conducted throughout all the design and development phases.

The GUI comprises a main menu displaying a set of button icons that give access to robot services (Fig. 2). Once the user selects an application different controls are available for data entry and navigation. Robot services were selected based on the results of two previous needs assessment studies\textsuperscript{12, 13}.

For the design of the main menu interface we conducted a preliminary study with a group of end-users to explore their preferences with regard to icon characteristics\textsuperscript{14}. Nine images were then selected to create the button icons representing robot applications (Fig. 2). According to users’ preferences it was decided to use images depicting real objects or actions and to present the buttons unlabeled.
GUI design, usability, acceptability
When designing GUIs for elderly users, it must be considered that cognitive and perceptual deficits may hinder the use of these applications\textsuperscript{14–16}. Having a limited computer experience constitutes an additional barrier for the adoption of such interactive systems\textsuperscript{15,16}.

Several studies have confirmed that older users face various difficulties when using some specific features of GUIs. Among the elements that have been associated to accessibility and usability problems in this population are\textsuperscript{17–21}:
- Cascading and other navigation menus
- Scrolling
- Images used as titles
- Insufficient visual contrast
- Links/button too small or too close to each other
- Icon comprehension
- Including too many links
- Moving content
- Pop-up windows
- Text that cannot be resized

Therefore, usability testing with representative end-users is a necessary procedure to identify usability barriers and to gain understanding on how users interact with technological applications. Guaranteeing GUI usability was fundamental in the QuoVADis project since robot services had to be accessed through the GUI when using the tactile interaction.

OBJECTIVES
The aim of this study was to assess usability and user’s satisfaction of graphical navigation elements of the robot’s GUI. Graphical elements included:
(i) Button icons
(ii) Navigation and menu controls

METHODS
Subjects
Eleven elderly persons with MCI and eleven healthy controls (HC) took part in this study. Participants in the MCI group were recruited through the Memory Clinic of Broca Hospital, those in the HC group were recruited through senior centers. All the participants volunteered for this study. French ethical committees CCTIRS and CNIL endorsed this project. Socio-demographic characteristics of the sample are presented in Table 1.

Table 1. Socio-demographic characteristics by group

<table>
<thead>
<tr>
<th>Group</th>
<th>MCI</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Gender</td>
<td>M=5; F=6</td>
<td>M=0; F=11</td>
</tr>
<tr>
<td>Age mean (SD)</td>
<td>76.63 (7.92)</td>
<td>76.36 (7.85)</td>
</tr>
<tr>
<td>Range</td>
<td>73-86</td>
<td>66-88</td>
</tr>
<tr>
<td>EL* (years)</td>
<td>&lt;7=5 ; ≥7=6</td>
<td>&lt;7=6 ; ≥7=5</td>
</tr>
<tr>
<td>PC experience</td>
<td>none=0; regular=5</td>
<td>none=4; regular=7</td>
</tr>
</tbody>
</table>

*EL= Educational Level

Material
Tasks were performed on the Tablet PC of the Kompaï robot (12” HD display WXGA, 1280 x 800). A stylus pen was used to input commands to the touch-screen. Sessions were recorded with two video cameras. A grid was used to score user’s performances. Data were analyzed with The Observer\textsupersoft{XT} software.

Procedure
Tests were conducted in individual sessions. First, the test moderator described the purpose of the research. All participants read and signed an informed consent form prior to enrollment. Afterwards, the moderator introduced the robot and the GUI. Participants were also instructed on the use of the touch-screen. Then, they were asked to complete a set of tasks that required the use of graphical navigation elements:
(i) Main Menu: icon comprehension test.
(ii) Shopping List: icon comprehension test and to enter two products in the list.
(iii) Agenda: enter an event (month, day, details, and confirmation).

Usability measures of graphical elements

Button Icons
(i) For each icon of the Main Menu (Fig. 2) the following aspects were considered:
- Interpretation of the function represented by each icon (1=accurate, 0= incorrect). Button icons were presented without text labels.
- Icon size (3 x 3 cm), use of unlabeled icons, and use of a homogenous palette color were rated using a binary score (1 = satisfied, 0 = not satisfied).

(ii) In the Shopping List application user’s interpretation of product category button icons was rated (1 = accurate, 0 = incorrect). Button icons were also presented without text labels (Fig. 3).

Fig. 3. Product category button icons. From left to right: Fruits, Vegetables, Meats, Beverages, Cleaning products.

Navigation and control menus

Usability of the following graphical navigation elements was assessed by measuring task duration and number of errors.

(i) Use of the NumericUpDown control to select the number of items by clicking on an up or down arrow in the Shopping List (Fig. 4). Task was repeated twice.

(ii) Use of graphical navigation elements in the Agenda:

(a) Back and forward arrows to select the month (Fig. 5).
(b) “PLUS” button to open the window to enter event details (Fig. 6).
(c) “ADD” button to confirm the appointment once event details were entered (Fig. 7).

RESULTS

Button Icons

Main Menu Icons

Results showed that approximately two-thirds (66%) of the participants gave an accurate interpretation of button icons (Fig. 8). However, there was a single exception concerning the Robot Control icon, which obtained a very low score (9%). Indeed, average score of accurate interpretation for all icons, excluding the Robot Control, was of 73.12%.

Among the icons that were accurately interpreted by the majority of participants were the Weather Forecast (81%), the Medication Reminder (81%) and Web Games (90%). Moreover, both groups (MCI and HC) were very similar in their percentage of accurate interpretation.

With respect to icons’ features, most participants found the actual icon size acceptable (72.7%). In contrast, few of them (18%) were satisfied with the use of unlabeled icons. Actually, the majority of respondents considered that the use of text labels could improve icon interpretation. Also, over half of the participants (54.54%) were satisfied with the use of a homogenous color palette.

Shopping list icons
Interpretation results of product category icons from the Shopping List were rather heterogeneous. Some icons obtained high scores: Fruits (100%), Vegetables (77.27%), and Meats (86.36%). In contrast, Beverages (54.54%) and Cleaning Products (36.36%) obtained middle-to-low scores.

Control menus

NumericUpDown control

Some difficulties were observed in both groups with regard to the first and the second use of the NumericUpDown control represented by the mean number of errors (Table 2). Still, participants in the MCI group were slower and made more errors than HC when using this element (Fig. 9, Fig. 10).

An interesting result was the reduction of number of errors when using the NumericUpDown for the second time, particularly for participants in the MCI group (Fig. 9). There was also a reduction in task duration for both groups between the first and the second use of the control (Fig. 10).

Graphical navigation elements in the Agenda

Results related to the use of navigation elements in the Agenda task, such as the Back and Forward arrows (B&F), the PLUS sign, and the ADD button revealed the difficulties that users experienced (Table 3). Older adults in both groups had some problems understanding the function of these navigation controls, in particular the B&F arrows to select the month and the PLUS sign to open the window for entering event details in the Agenda. However, comparing task duration for the use of the three navigation controls results showed that participants in both groups (MCI and HC) were faster when using the ADD button than the other two navigation controls.

Table 2. Mean values of task duration and number of errors (E) when using the NumericUpDown control for the 1st and 2nd time

<table>
<thead>
<tr>
<th>Group</th>
<th>Duration 1st use (s)</th>
<th>Duration 2nd use (s)</th>
<th>Duration 1st + 2nd (s) Mean</th>
<th>Errors 1st use (Mean)</th>
<th>Errors 1st + 2nd (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCI</td>
<td>22.2</td>
<td>10.7</td>
<td>16.4</td>
<td>0.9</td>
<td>0.18</td>
</tr>
<tr>
<td>HC</td>
<td>18.8</td>
<td>6.7</td>
<td>12.7</td>
<td>0.27</td>
<td>0.18</td>
</tr>
<tr>
<td>BOTH</td>
<td>20.5</td>
<td>8.7</td>
<td>14.6</td>
<td>0.58</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 3. Mean values of task duration and number of errors (E) in the use of navigation menus by group

<table>
<thead>
<tr>
<th>Group</th>
<th>B&amp;F (s)</th>
<th>B&amp;F (E)</th>
<th>PLUS (s)</th>
<th>PLUS (E)</th>
<th>ADD (s)</th>
<th>ADD (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>24.7</td>
<td>0.36</td>
<td>19.4</td>
<td>0.54</td>
<td>15.6</td>
<td>0.36</td>
</tr>
<tr>
<td>MCI</td>
<td>22.7</td>
<td>0.36</td>
<td>27.7</td>
<td>0.54</td>
<td>9</td>
<td>0.36</td>
</tr>
<tr>
<td>BOTH</td>
<td>23.7</td>
<td>0.37</td>
<td>23.63</td>
<td>0.54</td>
<td>12.32</td>
<td>0.36</td>
</tr>
</tbody>
</table>

DISCUSSION

In this study we assessed initial usability of some graphical elements of the interface of a social assistive robot. Taken as a whole results highlighted that older adults experienced particular difficulties when using some of these graphical elements for the first time but that they were capable to use the system after receiving some guidance. Furthermore, this study has provided us empirical evidence of GUI usability barriers that affect users' performance and that require some design modifications.

Button Icons

Correctly interpreting icons is particularly important to perform tasks with a GUI that uses these graphic elements to convey information. In our study results suggest that accurate icon interpretation was associated to the familiarity users had with the function or image depicted. The concreteness of the images, this means the representation of real world objects, seemed to contribute as well to icon interpretation. These observations are in complete agreement with
previous studies showing that familiarity and concreteness influence icon comprehension. For instance, in the Main Menu task, icons that obtained the highest interpretation scores represented familiar images for the participants (a sun for Weather Forecast, a syringe for Medication Reminder, and a chessboard for Web Games). On the contrary, older adults showed more difficulties understanding icons representing novel functions, such as Email, Cognitive Stimulation, and the electronic Agenda. In fact, the images used for these icons were more abstract and the link between image and function was in these cases less direct (e.g., a person finding the solution for a crossword puzzle for Cognitive Stimulation, an envelop with an @ sign for Email). Besides, interpretation difficulties observed with the Robot Control icon confirmed the importance of context when inferring the meaning of a symbol. In fact, in our study participants had never seen the robot in movement before the task.

Since older adults can exhibit difficulties in understanding the meaning of unfamiliar icons, it seems important to find alternative solutions to represent these novel functionalities. One solution could be the use of efficient metaphors involving familiar physical objects. In fact, since SAR constitutes a recent research field, it is very likely that older users lack knowledge about the functions a robot can provide. An interesting experiment could be to explore with representative end-users the semantic fields related to novel functions in order to decide the best pictographic representation. Another solution could be to study the retention of icons’ meaning over time, by conducting repeated assessments.

Concerning product category icons in the Shopping List interface, low interpretation scores for Beverages and Cleaning Products icons could be explained by the similarity between the two images used for these icons, which may have lead to misinterpretation. Besides, these icons had a small size (1.5 x 1.5 cm), factor that could have made difficult visual discrimination.

Related to icon’s feature (size, use of labels, colors), one limitation of our study was that participants were not confronted to alternative versions of the GUI (labeled icons, icons with differentiating colors). Users’ preferences were based exclusively on their opinion of how an alternative design would look like. When conducting usability assessments comparing alternative designs, GUIs that offer similar functionalities but different navigation layouts, could contribute to better assess users preferences.

Using text labels have proven to improve icon comprehension in elderly users. A similar effect should be expected for elderly with MCI. Besides, text labels could compensate memory deficits that can hinder usability. In this sense, a compelling research question is whether the use of labels would help to reduce the time a user requires to search for a particular icon on a display. Repeated observations could also help to understand if icon usability over time is more dependent on the use of text labels, images, or even on its position on the interface.

Control menus
Results suggest that difficulties faced by older adults concerning the use of the NumericUpDown Control, and the other navigation menus, were related to their lack of knowledge concerning GUI navigation. This is highly plausible since many elderly individuals have had very limited opportunities of learning to use computer-based systems. However, our results confirmed that learning to perform GUI basic actions is possible for elderly, either cognitively healthy or impaired. Some strategies could help to improve the understanding of navigation controls, for example in the Agenda task participants spent less time when using the ADD button than the other two, probably because the button was labeled.

As for previous GUI elements, we corroborated how important it is to study usability over time and not only in a first-use test, to explore the role of learning processes. Older adults benefit from repeated practice with guidance messages when learning to perform basic and complex operations with a computer-based system. In our tests the moderator provided guidance when the user made repeated errors. Automatic solutions should be conceived to offer a direct learning support through the GUI. One of the advantages of SAR is that Artificial Intelligence can be used to provide multimodal guidance for task execution in a robot-user collaborative relation (e.g., voice messages, speech-to-text recognition, engagement and emotional tracking).

**Conclusions**
Incremental design constitutes a useful method to develop technological applications for older adults since it permits to take into account users characteristics for the design of each GUI element.

This study is an example of a successful UCD process that helped us to identify key design features that will influence use of SAR and, specifically GUIs, by older adults.

**Acknowledgement**
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References

Tunnel boring machine positioning automation in tunnel construction

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Purpose Tunnel construction using a tunnel boring machine (TBM) entails precise machine positioning and guidance in the underground space. In contrast to traditional laser-based machine guidance solutions, the proposed research aims to develop an automation alternative to facilitate TBM guidance and as-built tunnel alignment survey during tunnelling operations.

Method A fully automated system is proposed, in which a robotic total station is employed to automate the continuous process of TBM tracking and positioning in the three-dimensional (3D) underground working space. ZigBee-based wireless sensor networks are applied for wireless data communication inside the tunnel. A camera is mounted on the telescope of the total station to capture online operational videos. Real-time survey data are thus acquired, processed and displayed on a tablet PC on the fly, resulting in: (i) TBM's precise coordinates in the underground space; (ii) three-axis body rotations of the TBM; (iii) tunnelling chainage progress; and (iv) line and grade deviations of the tunnel alignment.

Results & Discussion For proof-of-concept, a prototype TBM-positioning automation system has been developed in-house for laboratory testing. The accuracy testing was conducted by the automation system and a specialist surveyor independently. The differences between the two sets of surveying results were less than 2mm, which sufficiently validated the high accuracy of the automation solution. In April 2012, the prototype will be field tested on a 2.4 m diameter and 1,040 m long drainage tunnel project in Edmonton, Canada.

Keywords: automation, tunnel construction, TBM, machine control and guidance.

INTRODUCTION

For operators in the tunnel construction field, steering a tunnel boring machine (TBM) is like driving a vehicle in complete darkness. The current practice for TBM guidance largely relies on traditional laser guidance systems which project a laser point onto a target board fixed on a TBM. Limitations of the practice, however, potentially contribute to the high risks in executing tunneling projects, such as out-of-tolerance alignment deviations, project delay and budget overrun. Particularly, unforeseen underground obstacles and variable geologic conditions further complicate tunnel alignment control. It is not unusual that TBM operators and site managers are caught by surprise with excessive out-of-tolerance tunnel alignment errors 1. It may take weeks or longer time to determine the exact alignment deviations by survey specialists. Sometimes, the TBM can be trapped in the underground space, requiring considerable time, cost and effort for recovery; in worst-case scenarios, the TBM has to be abandoned in the ground due to prohibitively high cost of rescuing it. This research aims to develop an automation system for TBM positioning and guidance. A fully automated solution is proposed, in which a robotic total station is employed to automate the continuous process of TBM tracking and positioning in the three-dimensional (3D) underground working space. ZigBee-based wireless sensor networks are applied for wireless data communication inside the tunnel. Real-time survey data are thus acquired and processed on the fly, resulting in: (1) tunnelling chainage progress; (2) line and grade deviations of the tunnel alignment; (3) three-axis body rotations of the TBM; and (4) precise coordinates of any invisible points on TBM in the underground space. Further, the solution provides multiple role-based user interfaces and lends real-time, relevant assistance to TBM operators, tunnel surveyors, and project managers in making critical decisions.

The remainder of this paper is organized as follows: First, the pros and cons of the traditional laser guidance system are evaluated. We then illuminate system design of the proposed automation solution, followed by a tunnel estimation case to contrast improved and current work processes. Main findings and the practical applicability of the research are summarized in conclusions.

TRADITIONAL LASER GUIDANCE SYSTEM

Laser guidance systems have predominated in tunnelling applications for many decades. Generally, a
laser station is firmly fixed inside the tunnel, projecting a laser point onto a laser target board mounted on the TBM, as shown in Figure 1. Based on the offsets of the laser spot on the target board, the TBM operator infers the current line and grade tunnel alignment deviations.

Fig.1. Guiding laser beam inside tunnel

TBM's three-axis orientations in the underground space are crucial to machine steering control. Coupled with the traditional laser system, a two-axis bubble leveler is commonly installed on the TBM to gauge its rotation angles of pitch and roll in vertical planes. Meanwhile, the advancing direction of the TBM (yaw in the horizontal plane) can be determined through installing a transparent front target along with the rear laser target board (see Figure 2).

Fig. 2. Laser target boards mounted on the TBM: (a) transparent front target, (b) rear target

One of the major limitations associated with the traditional laser guidance system lies in relatively low accuracy and reliability due mainly to three factors, namely: (1) potential manual errors in initializing or calibrating the laser beam's alignment, (2) dispersion and refraction of the laser beam over a long distance, and (3) difficulty to receive laser's projection because of excessive TBM deviations. Typically, the maximum application distance for the laser guidance system is around 200 m. Besides, the laser beam's alignment toned to be frequently calibrated by specialist surveyors (at least once every other day). As a result, the tunneling productivity can be considerably undermined by operation and maintenance of the laser guiding system.

In order to facilitate tunnel alignment control, commercial companies have developed advanced TBM guidance systems by integrating sophisticated mechanical, optical and electromagnetic subsystems. Tight space constraints and harsh work conditions in the tunnel may not satisfy system installation requirements. On the down side, the high complexity in system design may compromise system reliability while considerably increasing the system's price and consumption cost, including system maintenance and technical service.

TBM POSITIONING AUTOMATION SYSTEM

The proposed TBM positioning solution combines four functions: (1) TBM tracking automation through surveying-computing integration; (2) wireless data communication enabled by ZigBee-based wireless sensor networks; (3) "virtual laser target board" program for TBM guidance; and (4) real-time visualization of tunnel construction in a 3D environment.

TBM tracking automation

The system employs a robotic total station to realize an automated, continuous process of TBM tracking and spatial data collection inside the tunnel, as illustrated in Figure 3. TBM's coordinates as well as its line and grade deviations from the as-designed tunnel alignment are computed in real time. By use of a limited quantity of tracking targets fixed on the TBM, the three-axis orientations of the TBM in the underground working space are computed by applying innovative “point-to-angle” algorithms, without the need of using any gauges (such as levelers, gyroscopes, inclinometers and compasses).

Fig.3. Automated target tracking for TBM positioning and orientations computing

Wireless data communication

Wireless sensor networks are purpose-deployed in the system design, enabling on-site data communication between key components of the TBM tracking system, namely, the total station, a control laptop computer in the underground tunnel, as well as a monitoring computer on the surface.
ZigBee-based wireless sensor networks are deployed in this system. In general, the emerging wireless sensor networks technology provides a smart, cost-effective and energy-efficient network infrastructure, which consists of a group of intelligent sensor nodes that can wirelessly communicate with one another. ZigBee represents a global specification for wireless sensor networks based on the IEEE 802.15.4 standard. Typically, the battery life of a ZigBee sensor node is around several months, which can be further extended to years under the “sleep” operation setting (analogous to setting a computer to the sleep mode).

In the field implementation of the proposed solution, a control laptop computer is placed adjacent to the steering panel of the TBM. One ZigBee wireless node is linked with the robotic total station through a serial data cable, the other ZigBee node with the USB interface is plugged in the control laptop, as shown in Figure 4. Real-time surveying results are transmitted to the computer, while remote control commands are forwarded to the total station through the same wireless data communication channel.

Fig. 4. Wireless sensor networks for data communication between the robotic total station and control laptop

Virtual laser target board program

A unique interface of the software system is a “virtual laser target board”, which is displayed in the control computer to guide the TBM. Four fundamental modules are integrated in the program, including (1) total station communication module (TSCM): this module handles wireless communication between the control laptop computer and the total station; TSCM controls the total station operations by executing preprogrammed point tracking and surveying commands, and translates the feedback from the total station in its “machine language” for further computing; (2) tracking and positioning computing module (TPCM): this module forms the core of the whole system and it computes TBM’s positions and attitudes from the coordinate data of the surveyed points. The computing results are passed over to the data publishing module; (3) analytical data publishing module (ADPM): the purpose of this module is to connect a data producer (for example TPCM) to a data consumer (for example the user interface module). It stores all analytical results in a queue and propagates any updates to all subscribers; (4) role based user interface module (RUIM): users of different roles have different user interfaces and each user interface has its own policy to render data.

The main user interface is designed for the TBM operator, which mimics a traditional laser target board the operator is familiar with, as shown in Figure 5. This user interface consists of (1) two perpendicular lines in the center of the screen and the crosshair indicating the as-designed alignment of the tunnel project; (2) two points onto the screen representing the current positions of the two center points at the tail and the head sections of the TBM, which are practically invisible in the underground space; (3) a square box which defines the TBM deviation tolerance limits. If the two points are both enveloped inside the box, it means at the current moment the TBM’s alignment deviations are well controlled within the specified tolerances. The Euclidean distances from the tail/head point to the two perpendicular lines define accurate measures of line and grade deviations of the tunnel alignment.

Fig. 5. Interface of virtual laser target board program

3D visualization of tunnel construction

A user-friendly 3D platform is provided in the system in order to visualize analytical results describing the TBM’s real-time position state, the tunnel design and the construction progress. It aids project managers in making critical decisions on a near real-time basis. The tunnel design and tunneling process are visualized in three steps: (1) before the construction phase, relevant environment data, like ground topography, strata information, geotechnical parameters, and the as-designed tunnel alignment are modeled in the system; (2) during the construction phase, the system reads TBM real-time positioning data and animates the construction process. The difference between the as-designed alignment and the as-built alignment can be readily visualized through 3D computer graphics, thus allowing project managers and engineers to monitor what is happening underground in an intuitive VR environment; (3) after the construction phase, the tunnel alignment control process and the as-built tunnel alignment can be reviewed, while the TBM operator’s experience can be captured for performance assessment and training purposes.
Figure 6 visualizes a simulated tunnel project. The progress of tunnel construction is presented in the complicated underground space, where the different colors of as-built tunnel sections indicate the quality of the tunnel alignment (green – within tolerance; red – out of tolerance).

**PRODUCTIVITY AND COST PERFORMANCE ANALYSIS**

In this section, a case study of evaluating productivity and cost performances on tunnel construction by use of the two alternative TBM guidance systems is presented. Suppose a 1,000-meter-long tunnel is to be built, total project time and direct construction cost are estimated for the traditional laser system and the proposed automation system, respectively. The tunnel crew consists of one Tunnel Supervisor, one Tunnel Forman, one TBM Operator, one Crane Truck Operator, two Tunnel Laborers (level II) and four Tunnel Laborers (level I). A survey crew consists of three surveyors, as given in Table 1. The tunnel crew works 8 hours/shift, 1 shift a day, 5 days a week. The survey crew works on the site by appointment only. Based on the use of the traditional laser system on previously completed tunnel projects and productivity analysis using historical data, the average production rate is determined to be 5 m/shift, which factors in different types of delays in connection with survey checking and alignment control.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Job</th>
<th>Hourly salary$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tunnel Supervisor</td>
<td>$ 33.544</td>
</tr>
<tr>
<td>1</td>
<td>Tunnel Forman I</td>
<td>$ 28.554</td>
</tr>
<tr>
<td>1</td>
<td>TBM Operator</td>
<td>$ 26.915</td>
</tr>
<tr>
<td>1</td>
<td>Crane Truck Operator</td>
<td>$ 25.536</td>
</tr>
<tr>
<td>2</td>
<td>Tunnel Laborer II</td>
<td>$ 25.936</td>
</tr>
<tr>
<td>4</td>
<td>Tunnel Laborer I</td>
<td>$ 25.148</td>
</tr>
<tr>
<td>3</td>
<td>Surveyor</td>
<td>$ 24.573</td>
</tr>
</tbody>
</table>

For the traditional laser system:

- “Routine survey”: In every 10 m TBM advances, a shutdown for 1.5 hours is necessary for routine checking of laser alignment by the survey crew;
- “Relocation survey”: In every 200 m a shutdown for 5 hours for laser station relocation and laser realignment by the survey crew is necessary, which includes any “routine survey” if needed;
- “Misalignment shutdown”: In every 800 m a potential shutdown for 1 week is required to fix TBM misalignment issues by the tunnel crew.

Note: the surveyors are only paid based on the number of hours they spend on survey checking and laser realignment services; while the equipment rental fee is charged based on time of availability on the site. Meanwhile, during non-productive shutdown periods, the tunnel crew would work on tunnel maintenance while still being paid by their hourly rates.

Given the average production rate of 5 m/shift, the total project time by use of the laser system is determined as:

\[(1000/5)*8 = 1,600 \text{ h}\]

The cycles as required for routine survey, relocation survey and misalignment shutdown are determined as below, respectively:

\[1000/10-1 = 99 \text{ cycles}\]
\[1000/200-1 = 4 \text{ cycles}\]
\[1000/800 = 1 \text{ cycle}\]

The total shutdown time is 196 h. Therefore, actual tunneling time is 1,600-196 = 1,404 h. Based on the information given in Table 1, the hourly wages for the tunneling and survey crews are calculated as $ 267.013 and $ 73.719, respectively. The direct labor costs for the tunnel crew and the survey crew are calculated as below, respectively:

\[1600*267.013 = $ 427,220.8\]
\[(141+15)* 73.719 = $ 11,500.164\]

Since the equipment rental fee is charged based on time of availability on the site, the equipment rental time is estimated as:

\[(1600/8)/5 = 40 \text{ weeks} = 6,720 \text{ h}\]

The direct equipment rental cost is:

\[6720*(315+120) = $ 2,923,200\]

In total, the direct project cost is $ 3,361,920.964.

For the proposed automation system:

- “Routine survey”: In every 50 m TBM advances, a shutdown for 1 hour is necessary for routine checking by the survey crew;
“Relocation survey”: In every 200 m a shutdown for 2 hours is required for total station relocation by the survey crew, which includes any routine survey if needed;

- Shutdowns due to misalignment fixing are not required.

Assuming the same tunneling hours are required on the project when the automation system is applied, the actual tunneling duration is 1,404 h.

The cycles for routine and relocation surveys are:

- 1000/50-1 = 19 cycles
- 1000/200-1 = 4 cycles

Considering the overlap between survey services and shutdowns, the durations for routine and relocation surveys are:

\[(19-4)\times 1 = 15\ h\]
\[4\times 5 = 20\ h\]

The total shutdown time is 35 h. Then, the total project time is 1,404+35 = 1,439 h.

As such, the average production rate using the automation system is:

\[
1000/1439\times 8 = 5.56\ m/\text{shift}
\]

The direct labor costs for the tunnel crew and the survey crew are:

\[
1439\times 267.013 = $384,231.707
\]
\[
35\times 73.719 = $2,580.165
\]

The equipment rental time is estimated as:

\[
(1439/8)/5 = 36\text{ weeks} = 6,048\ h
\]

The direct equipment rental cost is:

\[
6048\times (315+120) = $2,630,880
\]

Therefore, the direct project cost is $3,017,691.872.

Table 2 compares the total project times, the direct construction costs and the average production rates for the two TBM guidance systems. When the automation system is applied to replace the traditional laser system, the contractor would save $344,229 on the direct construction cost. Meanwhile, it is estimated that 10.1% shorter project duration and 10.2% lower direct cost would be achieved, while the average production rate would be increased by 11.2% to 5.56 m/shift.

<table>
<thead>
<tr>
<th></th>
<th>Laser system</th>
<th>Automation system</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project time</td>
<td>1600 h</td>
<td>1439 h</td>
<td>-10.1%</td>
</tr>
<tr>
<td>Direct construction cost</td>
<td>$3,361,921</td>
<td>$3,017,692</td>
<td>-10.2%</td>
</tr>
<tr>
<td>Production rate</td>
<td>5 m/shift</td>
<td>5.56 m/shift</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

**SYSTEM PROTOTYPING AND FIELD TESTING**

A prototype of the proposed automation system was developed in-house at the University of Alberta. The automation prototype mainly consists of three mini tracking targets (model: CTS Leica Compatible Mini Prism 65-1500M), a robotic total station (model: Leica TCPR1203+) and three ZigBee wireless sensor nodes (model: SENA ProBee ZS10 and ZU10), as shown in Figure 7. In close collaboration with the Design and Construction Section of the City of Edmonton, the new solution is scheduled to be implemented in a 2.4 m diameter and 1,040 m long drainage tunnel project in Edmonton, Canada for field performance evaluation from the end of April 2012.

![Fig.7. Prototype of the TBM positioning automation system: (a) three tracking targets mounted on a 2.4 m diameter TBM, (b) robotic total station linked with a ZigBee wireless node](image)

**CONCLUSIONS**

Increasing demands for better underground infrastructure have spurred tunnel construction all over the world, within which the TBM tunneling method is the most commonly applied. The lack of effective TBM guidance solutions, however, potentially contributes to increased risks and uncertainties in tunnel construction.

In this research, we have developed an automation solution for TBM positioning, which integrates automation control mechanisms, innovative computing algorithms, and wireless network technologies. Meanwhile, the multiple role-based user interfaces lend substantial decision support for TBM operators, tunnel surveyors, and project managers to track the construction progress as well as visualize any tunnel alignment deviations on the fly.

The project estimation case study indicates by adopting the proposed automation system tunneling productivity would be improved by 11.2% against using the traditional laser system. The resulting project duration and the direct construction cost would both be reduced by about 10%. The realistic system performances and the productivity improvement will be further validated through conducting extensive field experiments of the automated TBM positioning system at Edmonton, Canada starting from the end of April 2012.
ACKNOWLEDGMENTS
This research was substantially supported by the TECTERRA’s Alberta University Applied Research Funding Program (1108-UNI-008). The writers thank Mr. Sheng Mao and Mr. Xiaodong Wu of the University of Alberta for their deliberate effort and significant contribution in system development. The writers also thank Mr. Tim Schneider, Mr. Chris Pratt, Mr. Rick Edge, Mr. Darsh Wimal Nawaratna, Mr. Michael Yu, Mr. Ray Davis and Mr. Junhao Zou of the City of Edmonton for their help in conducting field trials.

References
Optimized Acceleration of Repetitive Construction Projects

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Purpose The purpose of this paper is to present an improved algorithm for optimized acceleration of repetitive construction projects. Method Through a set of iterative steps this algorithm identifies the least costly method that would put a project back on track, while maintaining crew work continuity. The algorithm divides each activity into segments and identifies the segments that would shorten project duration if accelerated. For these identified segments, the ones with the lowest cost slope are selected and cued for acceleration. Through the proposed segmentation of activities this algorithm provides better focusing of allocated additional resources, thus resulting in more cost-efficient acceleration plans. The algorithm is implemented in a spreadsheet application, which helps automate calculations, yet allows users to fine-tune the algorithm to fit the project conditions at hand. The algorithm allows users to select among different acceleration strategies such as working overtime, working double shifts, working weekends, employing more productive crews, work stoppage for converging activities and intentional work breaks. Results & Discussion The developed algorithm is applied to a case study drawn from literature in order to illustrate its basic features and demonstrate its accuracy. The results obtained, when compared to those reported for the case considered, demonstrate the ability to accelerate this project in while utilising fewer resources.

Keywords: management & social issues, repetitive projects, acceleration, linear scheduling

INTRODUCTION

In many cases contractors and/or owners find themselves challenged by having to accelerate a repetitive project. This challenge is difficult for two main reasons, primarily because the need for such a decision implies that the project is already running behind the required ending date, which increases the pressure on involved parties, and secondarily because accelerating a project implies enduring additional costs that are not accounted for in projects’ original budgets. These facts highlight the need for a reliable tool that would aid project managers in selecting the right action to accelerate a project at least cost in a timely manner.

Repetitive construction projects are identified as construction projects formed of recurring units, each unit consisting of a number of sequential activities. This unique nature paves the way for making considerable savings on time and cost by maintaining the continuity for crews and different resources involved in this class of projects. Maintaining work continuity offers many benefits such as maintaining a constant workforce by reducing firing and hiring of labour, retaining skilled labour, maximizing use of learning curve effect and minimizing equipment idle time. However, maintaining continuity forms an additional constraint when planning and managing a repetitive project. Consequently, using traditional scheduling and planning tools and techniques to manage repetitive projects has been widely criticized. This calls for developing special tools and techniques to properly manage every aspect of a repetitive project. The research at hand presents a unit based acceleration technique for repetitive construction projects. There are two main uses for the presented technique: it can be used to shorten a project’s planned duration if the project is scheduled to end after a specific deadline, or it can be used as a part of a control procedure when a project runs behind schedule, to reduce or eliminate schedule overruns.

IDENTIFYING ACTIVITIES TO ACCELERATE

Recognizing the right activity to accelerate in a repetitive project is key step towards successful project acceleration. Accelerating the wrong activity will lead to spending more money without any effect on a projects duration, or to spending more money than needed. In traditional projects (i.e. non-repetitive) such a decision is made easier by shortening activities on the critical path, where priority for activity crashing is set based on their respective cost slope. Consequently, crashing any activity on this path would shorten the projects duration. This remains valid until that critical path is no longer the longest path in the network. Things are different in repetitive projects, as many alternatives exist in literature for identifying which activities control a repetitive pro-
ject’s duration. Two well-known methods to identify the critical activities controlling a repetitive projects total duration are “Controlling Activity Path” for schedules built using Linear Scheduling Model (LSM)\(^4\), and “Controlling Sequence” for schedules built using Repetitive Scheduling Method (RSM)\(^6\). Many comparisons have been made between these two methods highlighting advantages and disadvantages of both methods. Although both successfully identify critical activities, both techniques only account for sequential activities with constant production rates, therefore limiting their practical use\(^{10}\).

Although in the context of this research Linear Scheduling Model (LSM) was used to represent schedules, a different technique was used to identify which activities to accelerate than targeting the controlling activities defined earlier\(^6\). The technique adopted in this research is a modified version of the technique proposed by Hassanein and Moselhi\(^8\). In their technique, identification of critical activities was set based on activities’ least alignment with their successors. As the case in all repetitive projects scheduling techniques, when a successor activity has a higher rate than its predecessor, its starting time is determined by backward calculations based on the predecessor activity ending time. Consequently, reducing the duration of a least aligned predecessor will advance its ending time, thus enabling an earlier start for its successor. Figure 1, shows an example of a repetitive project’s schedule, and shows how accelerating the least aligned activity would lead to shortening project duration. The proposed modification in this research is that the identification of the least aligned activity is performed for each unit separately. So instead of identifying an activity to be accelerated throughout all units, the activity to be accelerated is identified for each unit separately.

**ACCELERATING STRATEGIES**

There are common accelerating strategies project managers often use when accelerating repetitive projects. Acceleration strategies that are extracted from literature and included in the scope of this research mostly depend on increasing the man hours assigned to the activity. This can be done by choosing one of the following strategies: (1) working overtime; (2) working double shifts; (3) working weekends and (4) employing more productive crews\(^9\). These strategies aim at increasing the assigned man-hours to each activity; enabling the activity to be completed in shorter duration. Clearly each of the acceleration strategies stated above comes with associated costs. Examples of these associated costs are increased direct costs as in labor wages and equipment running costs, and indirect costs in the form of increased supervision and loss of productivity due to congestion in case of increased crews size\(^9\). On the other hand, as projects’ total duration decreases, indirect costs also decrease. Two additional strategies are also considered, namely: (5) relaxing activities\(^3\) and (6) introducing intentional work breaks\(^13\). Those two strategies can have the effect of decreasing projects total duration only if applied to converging activities. As can be seen in Figure 2, converging activities are activities having a higher rate than their predecessor and a lower rate than their successor. By relaxing a converging activity’s rate or introducing an intentional break it can start earlier, and its successor can start earlier. Relaxing an activity might cost less money as it leads to assigning fewer resources, however it might cost more. For example relaxing an activity could mean increased renting period for equipment and increased supervision man hours. Similarly introducing intentional breaks comes at an increased cost, especially in equipment extensive projects like highway projects as rented or procured equipment would be left idle on site. The associated costs leave strategies (5) and (6) less likely to be chosen by a project manager to accelerate a project; however, they are included as options in the proposed algorithm.

---

**Fig. 1. Effect of Acceleration on a Repetitive Schedule**

**Fig. 2. Acceleration by Relaxing a Converging Activity**
units. For example, chose to accelerate activity “earthwork” for every kilometre throughout a highway construction projects. This might be the correct choice in some cases where units are all typical. Typical units mean that for each activity all units have the same quantity and that crews and equipment have same productivity throughout all units. This leads to a repetitive schedule formed of activities represented by straight lines with a different slope for each line. Once an activity is identified to be less aligned with its successor or predecessor (i.e., critical), it will continue to be less aligned through all units. This is identified as a special case. The general case is that projects consist of non-typical units. Non-typical units have different quantities for the same activity, and utilize crews and equipment operating at different productivities. Repetitive projects schedules consisting of non-typical activities are represented by broken lines with varying slopes for each unit. An example of which can be seen in Figure 3. This general case makes it unlikely that the least aligned activity will be the same throughout all units. The presented algorithm in this research identifies the least aligned activity separately for each unit. By doing so, two main benefits are realized. Firstly, needed duration shortening can be achieved using less accelerating resources, as these excess resources were previously assigned to non-critical portions of the identified activity, thus not reducing total project duration. Secondly, it helps avoid productivity loss due to assigning too many overtime hours, as literature shows that maintaining a 1 hour per day of overtime for 4 weeks, results in a 16% less efficient process than keeping regular working hours for 4 weeks.

PROPOSED METHOD

The proposed acceleration technique aims at identifying which activities of a repetitive project to accelerate and which accelerating strategy to be used to accelerate them. The starting point is a repetitive project scheduled in LSM, and having a duration that needs to be shortened. As explained earlier, the priority in acceleration is for the activity that is least aligned with its successor. Identifying the least aligned activity is done using a technique similar to minimum moment algorithm used for resource leveling. It operates by calculating the areas trapped between lines representing successive activities, then calculating the moment these areas cause around a centerline. Less aligned activities result in bigger areas with bigger eccentricities, hence resulting in bigger moments, and vice versa. One of the modifications introduced in this research is that the alignment calculations are carried out for each unit separately instead of the whole project. Although this requires more calculations, yet it allows choosing less costly acceleration strategies.

A deeper look at the algorithm at hand reveals that considering each unit separately has a weakness. This approach would identify the criticality of an activity based only on the productivity of the assigned crew, regardless of the number of crews working on the same activity in other units. For example if 3 crews are assigned to an activity each producing 1 unit per day, their total productivity is 3 units per day. Comparing each activity’s rate and neglecting the global perspective that includes the number of assigned crews would identify this activity to be more critical than an activity assigned to a single crew producing 2 units per day, although clearly the later activity progresses at a slower rate. To address this issue the equations for calculating areas and their moment around the center line had to be modified to include also the number of crews, which enables correctly conveying the rate of an activity according to the productivity and number of crews assigned. The algorithm outlined in Figure 4 along with the following equations demonstrates how to identify the least aligned activity in a repetitive project is formulated. The activity with the largest value for $\Omega$ is the least aligned activity.

$$\Omega(i) = Area(i) \times e(i) - Area(i+1) \times e(i+1)$$

Where

- $Area(i)$ is the area between activity $(i)$ and $(i-1)$
- $S_{i}$ is the start time of activity $(i)$
- $S_{i-1}$ is the start time of activity $(i-1)$
- $F_{i}$ is the end time of activity $(i)$

![Fig.3. Typical and Non-typical Activities](image)

<table>
<thead>
<tr>
<th>Time</th>
<th>Typical activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>Non-typical activity</td>
</tr>
</tbody>
</table>

\[ L.Side(i) = S(i) - S(i-1) \]
\[ R.Side(i) = [F(i) - F(i-1)] - [D(i)(n-1)/n] + [D(i-1)(n'-1)/n'] \]
\[ e(i) = C(i) - 0.5 \]
\[ e_{i+1} = 0.5 - C(i) \]

580
• $F_{i-1}$ is the end time of activity $(i-1)$
• $D_i$ is the duration of activity $(i)$
• $D_{i-1}$ is the duration of activity $(i-1)$
• $n$ is the number of crews assigned to activity $(i)$
• $n'$ is the number of crews assigned to activity $(i-1)$
• $C_i$ is the distance between the area’s edge to the area’s center of gravity
• $e_{i}$ is the eccentricity of the center of gravity to the center line of area $(i)$
• $\Omega(i)$ is the value reflecting the degree of misalignment of activity $(i)$

The formulated model was implemented in a spreadsheet application that automates all calculations. The application accepts projects initial schedule, along with activities quantities and crews rates. It automatically runs all calculations and identifies the activity nominated for acceleration in each segment. As the user responds to the identified nominations and assigns acceleration resources, the application continuously re-identifies the next activity to be accelerated in each segment, until the required duration reduction is achieved.

**CASE STUDY**

The developed algorithm was applied to a case study drawn from literature to demonstrate its basic features. The case study presented in literature\(^2\) is a 15 Km three-lane highway project, consisting of 5 repetitive activities. These activities, in their order of precedence, are: (1) cut and chip trees; (2) grub and remove stumps; (3) excavation; (4) base; and (5) paving, and all precedence relations are finish to start, with no lag time. The project is divided into 15 segments of equal lengths, each is 1 km. This project includes typical activities and non-typical activities. Typical activities are (4) base and (5) paving, as they...
have same quantities for each unit and same crew productivity for different crews. While activities (1) cut and chip trees, (2) grub and remove stumps and (3) excavation are non-typical activities, as their quantities change from one unit to another and also their different crews have different productivities. The included activities are all sequential except for activity (3) excavation; this activity is non-sequential as its starts by units 4 to 1, then units 5 to 15. The original project data can be found in literature\(^2\), the initial schedule had a normal duration of 83 days.

When Hassanein and Moselhi\(^7\) applied their acceleration technique, the goal was to accelerate the project to end it in 77 days. And they only considered working overtime hours as an acceleration strategy, and the cost of overtime hours was considered the same for different crews. So the case study was mainly about identifying which activities to accelerate. Their acceleration technique achieved the required end date by accelerating activities “grub and remove stumps” and “excavation” throughout all units, by adding three and two hours of overtime per day respectively. The total of the assigned overtime hours mounts up to 75 hours.

The algorithm proposed in this research was then applied to the selected case study. The original schedule was input to the developed spreadsheet application. The spreadsheet automatically identifies the critical activities to be considered for acceleration for each respective unit. Additional overtime hours were added to the identified activities. Automatically the schedule was updated and the new critical activity segments were identified and additional overtime hours were added in an iterative manner, taking into consideration the limit of available overtime hours for each crew. The final 80 days duration schedule was achieved by the combination of overtime hours displayed in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Added Overtime Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut and chip trees</td>
</tr>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
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<td>13</td>
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<tr>
<td>14</td>
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<tr>
<td>15</td>
</tr>
</tbody>
</table>

Table 2 shows the original duration and results of both acceleration methods. It can be seen that the modified acceleration algorithm presented in this research achieved the same duration reduction by assigning 46 instead of 75 overtime hours, thus significantly reducing acceleration costs.

<table>
<thead>
<tr>
<th>Table 2: Comparison of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule</td>
</tr>
<tr>
<td>Original Schedule by Elrayes(^2)</td>
</tr>
<tr>
<td>Acceleration by Hassanein and Moselhi(^7)</td>
</tr>
<tr>
<td>Modified unit based acceleration</td>
</tr>
</tbody>
</table>

**CONCLUDING REMARKS**

An improved algorithm for optimized unit-based acceleration of repetitive construction projects was
presented. The presented algorithm can accommodate typical and non-typical activities, and sequential and non-sequential activities. The automated spreadsheet application presented makes using the algorithm very simple and straightforward, and allows users to fine tune the algorithm to fit any project conditions at hand. The presented method selects from six available alternatives for project acceleration while maintaining resource continuity. The demonstrated application to a case study showed how the presented works well for accelerating construction of repetitive projects; yielding —for the case study— the same accelerated project duration while using less additional resources.

REFERENCES
Virtual Reality for Persons with Dementia: an Exergaming Experience

Mauro Colombo 1,2*, Eleonora Marelli 1,2, Roberta Vaccaro 2, Eleonora Valle 2, Savina Colombani 1, Elisabetta Polesel 1, Sabrina Garolfi 3, Silvia Fossi 2, and Antonio Guaita 2

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Purpose  Cognitive stimulation may improve quality of life for people with light to moderate dementia. We explored feasibility and results of video gaming for persons with dementia, in terms of acceptability and pleasure. We argued that participants could experience fun and engagement in a context of supervised physical activity. As a secondary goal, participants’ cognitive performance might benefit from such exercise. Method A total of 10 patients in our long-term special care units were screened according to their ability and their will to engage with videogames; cognitive impairment ranged from severe to mild [crude Mini Mental Status Examination (MMSE 11-24); balance ranged from impaired to almost normal (Tinetti balance 6-15), and gait ranged from impaired to normal (Tinetti gait 3-12). Withdrawal and social interactions were measured by a-MOSES scale and ranged from 25 (worst) to 17 (best). Persons with dementia were invited by a trainer to exercise their upper limbs by blowing up blue bubbles from a screen that captured the image of the person. Sessions were held twice weekly in quiet rooms. Exergames were shown stepping through increasing difficulty levels (different colours, speed of movement, bi-manual dexterity required). Exergames (EyeToy: play for PlayStation2) were played from a console that had an USB-camera placed on the top of the TV reproducing the person on the screen. The screen displayed a background on which the target stimuli, the blue bubbles, were presented together with red bubbles that must not be scratched. When the first stages of the game were executed correctly, the game proceeded to levels of increasing difficulty. In the easier levels the player had to make a visuospatial analysis and attentional monitoring of the action: in this stage the arm movements can be inaccurate. In the upper levels, problem solving, action planning, praxis abilities, motor coordination and psycho-motor speed are also involved. Results & Discussion Subjects played from 2.416” to 14.400” (mean 8.535”, SD 4.098”); they achieved difficulty levels ranged from 3rd (moderate) to 7th (top level), during sessions lasting from almost 4’ up to 20’ (longest duration allowed). Highest difficulty levels achieved correlated to spared ability levels in activities of daily living; no correlation was found with motor, cognitive or behavioural variables. Balance, gait and behaviour were no different at the end of the trial. Adjusted mean MMSE increased from 16.4±4.6 to 18.0±4.6 (p<0.05 by Wilcoxon paired sample test). Overall, persons with dementia participated well; they took an interest in the game. Technical subjects appreciated the game, which they perceived as a tool to improve their health and mobility, when playing them they usually implicitly remembered previous sessions. Motor performances improved especially in subjects interested in the game from the outset. No adverse events occurred, with special regard towards behavioural and psychotic symptoms, staff created a pleasant atmosphere while supervising and gently helping when needed, so that the behaviour was appropriate and cooperative. In conclusion, our preliminary experience shows that exergaming for persons with dementia may be proficient towards selected patients. Both our intended outcomes (acceptability-leisure, and cognitive benefit) were achieved. Results concerning cognitive improvement must be considered with caution.

Keywords: virtual reality, persons with dementia, exergames, leisure

INTRODUCTION

BACKGROUND

Patients with Alzheimer’s disease are notable for the wide range and severity of their cognitive deficits. Neuropathology may support deficits in visuospatial selective attentional mechanisms that are affected in specific dementing diseases like Alzheimer’s disease. Testing the processing of motion cues by computer animation sequences (random-dot cinematograms), mild to moderate Alzheimer’s disease has significant effects on the perception of structure from motion, with relative sparing of motion direction discrimination. Such deficits – based onto cerebral and retinal degenerative changes – have the potential to affect navigation and the recognition of objects in relative motion, as encountered during walking and automobile driving. In Alzheimer’s disease patients, the working memory store is impaired, slowing mnemonic consolidation and destabilizing feedback circuitry. Attentional control in Alzheimer’s disease is characterized by specific dual-task processing deficits. More, demented persons generally have shorter step lengths, reduced gait speed, lower...
stepping frequencies, and greater step-to-step variability than cognitively intact older adults. Individuals with Mild Cognitive Impairment perform worse than normal elderly on tasks involving fine and complex motor function, like tracking and manual dexterity. Early Alzheimer’s disease patients exhibit motor dysfunction on tasks assessing relatively more rudimentary motor control. In early stages of Alzheimer’s disease, response latencies prior to gesture execution is longer, the effect being prominent for transitive tasks and nondominant hand use. Imputing the words “virtual environments dementia” in PubMed retrieved 18 results, exploring a wide array of issues, spanning from neuropsychological assessment, to neuroimaging; special regard is devoted to spatial navigation and way-finding abilities, as well as to outdoor environment evaluation. Ethical issues are concerned, aside with rehabilitation of special functions, like visuo-constructional abilities. Literature supports the possibilities of computer stimulations to bring leisure, a feeling that is seldom experienced by persons with dementia. Usually - even early in the course of the illness - their lives are disrupted by behavioral and psychotic symptoms, which often upset their caregivers too. According to latest Cochrane Dementia and Cognitive Improvement Group Specialized Register (called ALOIS – updated 6 December 2011), cognitive stimulation may improve quality of life of people with light to moderate stages of dementia.

**Purpose**

Therefore, we aimed primarily at exploring the feasibility and the results of video gaming for persons with dementia, in terms of acceptability and pleasure. We argued that participants could experience fun and engagement in a context of supervised physical activity. As a secondary goal, participants’ cognitive performance might benefit by such exercise.

**METHOD**

10 patients assisted in our Long Term Special Care Units were screened according to their ability and their will to engage with videogames; cognitive impairment ranged from severe to mild [crude Mini Mental Status Examination (MMSE) min = 11/30 - max = 24/30]; balance ranged from impaired to almost normal (Tinetti balance min = 6/16 – max = 15/16), gait ranged from impaired to normal (Tinetti gait min = 3/12 – max = 12/12). Withdrawal and social interactions were measured by MOSES scale: ranges spanned from 25/34 (worst behavior) to 17/34 (best behavior). Persons with dementia were invited by a trainer to exercise their upper limbs by blowing up blue bubbles from a screen where the image of the person was captured in. Sessions were held twice weekly in quiet rooms. Exergames were shown stepping through increasing difficulty levels (i.e.: different colors, speed of movement, bi manual dexterity required). Exergames (Eye Toy; play for PlayStation2) are played from a console that has an USB camera placed on the top of TV reproducing the person on the screen. The camera detects the movements of the person allowing to interact with the action on the screen. The screen displays a background on which the target stimuli, the blue bubbles, are presented together with red bubbles that must not be scratched. If a large number of red bubbles is scratched, the game is over but you can try again in a new game session. When the first stages of the game are executed correctly, the game proceeds to levels of increasing difficulty. In the subsequent levels stimuli come casually from the top or bottom of the screen, from right to left and vice versa. In addition, they move with increasing speed. In the easier levels the player must make a visuospatial analysis and attentional monitoring of the action: in this stages the arm movements can be inaccurate. In the upper levels, problem solving, action planning, praxis abilities, motor coordination and psycho-motor speed are also involved.

**RESULTS**

Subjects played from 2.416” to 14.400” (mean 8.535”, s.d. 4.098”); they achieved difficulty levels ranged from 3rd (moderate) to 7th (top level), during sessions lasting from almost 4’ up to 20’ (longest duration allowed). Highest difficulty levels achieved correlated to spared ability levels in activities of daily living; no correlation was found with motor, cognitive or behavioral variables. Balance, gait and behavior didn’t change at the end of the trial. Adjusted mean MMSE (s.d.) increased from 16.4/30 (4,5) before virtual environment engaging to 18/30 (4,6) after it: p <.05 by Wilcoxon paired sample test. Overall, we got a good level of involvement by persons with dementia, who looked interested towards the game and tech. Subjects appreciated the game, which they perceived as a tool to improve their health & mobility, by playing; they usually implicitly remembered previous sessions. Motor performances improved especially in subjects interested in the game since the beginning. No adverse events occurred, with special regard towards behavioural and psychotic symptoms: staff created a pleasant atmosphere while supervising and gently helping when needed, so that the behaviour was appropriate and cooperating.

**DISCUSSION**

Recent literature remarks that patients with Alzheimer’s or vascular dementia who engaged in physical activity had fewer neuropsychiatric symptoms than those who did not. When compared to the control group, the caregivers of patients with vascular dementia who engaged in physical activity had a reduced burden. In conclusion, more and more
sophisticated exergames are on the rise in the marketplace as well as in academic research. Our preliminary experience show that exergaming for persons with dementia may be proficient towards selected patients. Both our intended outcomes (acceptability-leisure, and cognitive benefit) were achieved. Our proposal looks feasible and welcomed, as other technological engaging environments. Technology may help in creating proper environments, capable to drive favourably behaviours determined by damaged brains. In dementia, the perception of the environment stems from lower hierarchical brain levels compared to normal people. Environmental incentives have to be simplified, in order to prevent misunderstanding and related misbehaviours, and to empower the control of perception by persons with dementia. Exergames may build up pleasant virtual environments benefiting both wanderers and passive subjects. Results concerning cognitive improvement must be considered with caution. Yet, moderate intensity aerobic exercise is effective at reversing hippocampal volume loss by 1-2 years, in late adulthood, which is accompanied by improved memory function. Cybercycling improved composite executive functions over and above traditional exercise, and achieved a 23 % relative risk reduction in progression to clinical MCI (Mild Cognitive Impairment). For the same effort, cybercycling enhanced neuroplasticity, as from higher BDNF (Brain Derived Neurotrophic Growth Factor). Low intensity coordination exercises can benefit cognitive function of older adults. The “prosthetic approach” we envision is focused on well being, yet, cognitive advantages may follow, according to the literature. As in any rehabilitation effort, besides compensatory procedures to improve activities of daily living despite perceptual limitations, therapy may be directed to actual restoration of perceptual dysfunctions through stimulating central nervous system change. Motor stimulation – within a highly standardized multicomponent group intervention conducted in a nursing-home setting – was able to postpone a decline in cognitive function in patients with primary degenerative dementia.

CONCLUSIONS
Improvements in motor performances through this arm-raising paradigm of upstanding focal rapid reaching movements towards a target agrees with recent results demonstrating that feed-forward control to predict and compensate for self-generated perturbations may be improved in frail elderly.

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References


Estimation of job-site work progress through on-site monitoring

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Purpose This paper reports on the development of intelligent probabilistic models for real-time estimation of construction progress, which operate on the basis of a continuous data flow collected by monitoring networks deployed on-site. Several authors listed the advantages that would be provided by the availability of such models, like project performance and quality control, timely onsite inspections, better control of health and safety prescriptions against job injuries and fatalities. The findings reported in this paper represent a feasibility study and preliminary examples of Bayesian Networks, which are able to infer the work progress attained at every step, starting from real-time tracks of the construction site activities. Activity tracks are represented as a set of state variables figuring out workers’ effort, equipment and materials usage rates and other knowledge about the context.

Method As estimations are always related to dynamic processes, Dynamic Object Oriented Bayesian Networks have been used to develop a set of first order Hidden Markov Models. Hence, the models are arranged as a sequence of time steps, where each time step propagates evidences collected by the site monitoring sensor network along the time line. The actual cumulative progress is computed as a function of the progress achieved in each time step. Models representing a number of typical tasks (external piping, on-site cast of reinforced concrete floor slab, walls erection, ceiling installation) for a real case of a construction site have been developed. Their structure has been designed as part of a general monitoring framework, covering all the phases from design to execution, where BIM design, monitoring systems, methodological process innovations, intelligent inferences and advanced visualization are combined.

Results & Discussion The networks have been developed and validated through data collected from a real case, and they have been shown to be able to infer work progress, the accuracy of which depends on the resolution and quality of the collected data.

Keywords: automation, Bayesian networks, work progress, construction sites

INTRODUCTION Among the outstanding benefits that would derive from automated on-site workers, equipment and material tracking, real-time work progress estimation is considered as one of the most critical. Most of the ongoing research on this field, which is summarized in the next paragraph, is targeted to the following three main goals:
• setting up a cost-effective construction project management, featuring real-time deployment of information, including material and equipment inventory and their traceability;
• performing intelligent waste management, which makes its delivery to the appropriate facility for reuse, recycling, recovery or disposal feasible;
• providing a safe working environments to employees, whose translation into practical situations may be in the form of automated control of proper wearing of safety gears, signaling hazards in real-time, automated predictive collision detection and fall hazards warning in crowded site’s areas, and so on depending on the particular kind of work to be performed.

The main focus of this concerns a methodology, based on the use of advanced probabilistic models (Bayesian Networks) and real-time and low-invasive monitoring networks, to automatically estimate the work progress at the execution phase. In particular, the construction of a shopping mall made up of a precast concrete technology has been considered, and the feasibility of a monitoring approach for work progress estimation and based on the automated detection of those resources present on site has been shown. Moreover, this research step is part of a wider approach aiming at the development of an integrated framework for advanced construction management. Effective monitoring is conditioned upon embedding non-invasive sensors within resources which are expected to operate on-site. To this aim, BIM-based engineering design constitutes a fundamental support, because it allows the disaggregation of any building’s design into its elements and phases. In the proposed example a kind of tasks list has been pre-
liminary arranged through BIM, making the assignment of one or more sensor kit to each phase of the construction plan easier and faster (Fig. 1). Once resources and relevant variables are tracked, data collected can be filtered and processed in real-time by advanced probabilistic models, in order to infer the work progress, so that higher reliability and efficiency in Project Control reporting (e.g. Daily Site Reports) and quality inspection management can be achieved.

![Fig. 1. Interoperability for work progress management.](image)

The next paragraph reports about the most relevant research in this field. The following paragraph discusses the conceptualization of the whole framework. Following the details of a case study will be described. Conclusions close the paper, before the list of references.

**BRIEF OVERVIEW OF THE SCIENTIFIC BACKGROUND**

On-site tracking is seen as much challenging as promising, thanks to the many advantages that would be brought into the construction process: material management and inventory traceability, automated waste management (i.e. automatic recognition of the waste destination and its cycle), safety support through real-time laborers' warning in case of imminent and probable risk occurrence (e.g. collision avoidance, fall from heights etc...). Assisted design can help avert accidents at the design phase, but a real-time warning system is anyway useful to avoid unexpected or difficult to model occurrences.

Automated progress monitoring would reduce the burden of work usually required to produce project reports editing, and would make easier communication through automated visualization of construction data. Information awareness is an undisputable excellent tool to manage machines, as it can record operators and operational times in a central server, planning and ensuring inspection and maintenance. However, general economic efficiency is conditioned upon the development of a system for automated project performance control, where indirect data would be intelligently converted into performance measurements. The availability of such an approach would pave the way to many innovations, and several contributions in literature stressed those ones related to quality management: automated remote inspection of infrastructures; control of the construction quality of details that are no more visible after the task is accomplished (e.g. to validate the depth of foundation piers); tracking and understanding the context for automated relevant information retrieval during site inspection.

This paper contributes to the use of advanced probabilistic models (namely Dynamic Bayesian Networks) to perform inference from real-time collected data about the estimation of on-site work progress.

**THE CONCEPT**

The work progress estimation process, we are going to discuss, is part of a more comprehensive framework (Fig. 1) made up of interrelated technologies, which all together figure out an automated construction management system. Within this framework, the work progress monitoring function is the result of a management procedure that encompasses many different technologies. As depicted in Fig. 2, initially the construction process is broken down into basic activities, so that the resources used in each of them can be unambiguously identified. BIM-based engineering design can be used to support this task, since BIM object oriented modeling allows activities and resources to be clearly identified and assigned to design objects, such as building components and technical systems. A set of sensors is then assigned to each resource so that real-time data about the resource usage can be gathered. Given the research results and experiences about on-site materials and laborers tracking reported in the previous paragraph, and given the ongoing technology innovations, at present data about on-site resource usage, gathered in real time by embedded monitoring networks, can be considered sufficiently reliable to support management tasks.

Hence resource usage data is then processed by intelligent algorithms, capable estimating the progress of the ongoing activities. The results are finally arranged in a management database so that further elaborations, including scheduling of real-time inspection and quality assessment, as labeled in the fourth phase of Fig. 2, can be performed.

In the next paragraphs we will discuss the feasibility of automated progress monitoring by means of Dynamic Bayesian Networks, which is the key algorithmic step of this procedure, through a case study.
CASE STUDY
The construction site and monitored tasks
The resource usage data, the will be feed to the progress estimation algorithm, have been collected by monitoring the execution of a shopping mall in the village Cerreto d’Esi (AN), built by the company Torelli & Dottori SpA. The whole project includes three areas: the shopping mall, the office building and the parking lot. Our monitoring was relative to the erection of the shopping mall, which is on the left side of Fig. 3.

The squared shaped mall has a total surface exceeding 9,000 m², external height 6.90 m and internal net floor-to-ceiling height 3.50 m. It is made of precast concrete bearing frames; the roof is made of precast concrete floor slabs, walls made of concrete panels and aluminum framed windows. It is provided with a conditioning system, a solar heating system, a fire protection system, electric and lighting systems. Three tasks have been monitored during the execution:

- excavation and pipelines laying (sewage, electrical power line, water supply), both external and internal;
- site cast ground floor concrete slab;
- fabrication of internal hollow brick partitioning walls.

During excavation (Fig. 4a) the following state variables have been collected: rate of usage and position of excavators; usage and positions of dumpers; number of man-hours used to operate equipment, to lay pipes underground and to fill in trenches; number of pits laid underground. In addition, every half a day the actual work progress for the task was measured by our operators in charge of monitoring. Collected data extend from Monday 2011, July 18th to Thursday 2011, July 21st, when the task was accomplished. The site cast ground floor concrete slab execution took place between Tuesday and Wednesday 2011, July 26th–27th (Fig. 4b): first of all reinforced bars have been put in place (through the use of dumpers to transfer them from storage areas) and laborers and formworks were installed along the boundaries; then concrete was brought to the site by concrete truck mixers and poured in the formwork through the use of one concrete pumping truck setup on-site. So the usage of all the equipment and man-hours were monitored and recorded, together with work progress.
The hollow brick partitions were executed indoor (Fig. 4c) during 9 working days split into two phases: from Monday 2011, August 1st to Thursday 2011, August 4th and then again (after summer holidays) between Tuesday 2011, August 30th and Tuesday 2011, September 6th. In this case equipment (small dampers to move bricks from storage to the interior and concrete mixers to produce mortar) and number amount of bricks employed constituted relevant indicators for work progress estimation, together with employed man-hours.

Data gathering
As relevant variables for work progress monitoring were not know a-priori before the development of probabilistic models, monitoring was performed by operators observing the work progress and writing down records every 5min relative to the use of the resources listed above. This approach allowed redundancies and boost awareness on the procedures performed on site. So for each of the monitored tasks the following documents have been produced:
- a database comparing the work progress with the amount of resources employed during a time duration of 5min;
- reports with description of the work performed and monitored data;
- a photographic survey of the activities.

As the Dynamic Bayesian Network presented in the next paragraph is relative to the excavation and pipe laying task, Table 1 shows the data collected and reworked after such monitoring.

A pre-processing phase showed that a sampling time of one hour is short enough to capture all the relevant dynamics of the monitored activities. In addition the task under analysis has been subdivided into the three sub-tasks:
- trench excavation;
- laying of pipelines on a concrete bed;
- trench filling with sand and previously excavated ground.

That’s because the overall work progress of the main task resulted in fact from the composition of the work progress of these sub-activities. Therefore the data initially recorded have been resampled with a time scale of 1 hour (i.e. the time of equipment usage and the man-hours has been summed). Photos, site reports and measurements allowed to assign the actual work progress to each working hour. The data in Table 1 have been consequently organized through 41 rows (one for each hour) and 9 columns: three devoted to the work progress of each sub-task and other six devoted to resource usage during their execution. These data have been used to train the Dynamic Bayesian Network Model, as it will be discussed in the next section.

### DEVELOPMENT OF THE PROBABILISTIC MODELS

#### Dynamic Bayesian Networks

Bayesian Networks (BN) have the unique capability to provide both intuitive and scientifically rigorous representations of complex systems. In addition, after validation, they can be used for performing both scenario analyses, through inference propagation algorithms, and diagnostic reasoning, through backward propagation based on the inversion rule. These networks also have the advantage of enabling qualitative and explicit representation, where nodes represent variables and arcs represent quantitative relationships among the same, worked out through parametric probabilistic models.

When the domains to be modeled are very complex, Object Oriented Bayesian Networks (OObN) are usually used: they are made up of several elementary networks, sharing some of the variables, which constitute the links between the networks. Each elementary network is generally developed separately (and models one of the involved many physical phenomena) but the inference algorithms are propagated over the whole set of elementary networks.

Dynamic Bayesian Networks (DBN) are used to represent statistical models that depends on time, usually called stochastic processes. DBN are based on a discretized time line, and are made up of several time slices, each representing a snapshot of the state of the system at a particular moment in time. Transition relationships among different state variables in different time slices capture the system temporal dynamic. The application of BNs to model the
evolution of processes that have temporal dynamics requires, in its simplest formulation:
- an initial instance of the Bayesian network that contains the formulation of the problem at time \( t=0 \), that is the set of random variables \( X_{i,0} \) and the related conditional probability distributions: \( P(X_{i,0}|X_{i-1,0}), P(X_{i-1,0}|X_{i-2,0}), \text{etc.}; \)
- one or more transition networks that correlate the variables of the BN instance at \( t=0 \) with the variables of the BN instance at \( t=1 \).

Fig. 5 shows a graphical representation of three time slices of a DBN.

Two assumptions are usually made about the physical processes at hand:
- all the information needed to predict the state of the process at time \( t+1 \) is contained in the description of the process state at time \( t \). No information about earlier time is needed. These kinds of processes are called Markov processes of order one;
- the process is steady, that is, the transition networks remain the same for any \( t \rightarrow t+1 \).

The BN for work progress estimation
Fig. 6 depicts a plot of the work progress versus man-hours in the case of excavation sub-task. Similarly to the other sub-tasks (laying of pipelines and trench filling) it’s clear that no functional dependence can be defined established by the two variables, Hence the processes must have be modeled as stochastic Markov processes. Both first-order and second-order Markov networks have been tested, showing that the second worked better.

Then the dataset in Table 1 has been rearranged to replicate each variable in the four time slices (e.g. \( L_0, L_1, L_2, L_3 \)) with a shift of 1 hour each time slice and NPC structural learning performed. This algorithm allowed us to test whether other conditional dependence relationships occurred among each pair of variables, through an independence test, which is performed according to equations.
Referring to eq. (1), it is run on a dataset of \( n \) records, where \( x_{ij} \) is any record. \( x_i \) is every observation where \( x \) is found with a given value and the same holds for \( x_{ij} \). If the two variables are conditionally independent, their mean value for the generic \( x_{ij} \) must be given by equation (1). Eq. (2) holds on the same bunch of theory, but considers marginal probability distributions where dependence of the variable \( x_i \) from \( x_j \) is surveyed once the value of \( x_k \) is given. The use of eqs. (1) or (2) depends on the kind of qualitative relationships assumed among the variables. The statistics is distributed as a "chi-squared".

After performing the test with the help of Hugin Expert\textsuperscript{TM} software, in the network of Fig. 7 more causal relationships (given by arrows) as in Fig. 8-a were added. Similarly, it was done for the other sub-networks: pipelines laying (Fig. 8b) and trench filling (Fig. 8c).

At this juncture the dataset was used to perform EM learning\textsuperscript{16} for each sub-network: this kind of learning is capable of estimating multivariate "Dirichlet" distributions describing every conditional relationships in the network, the order of the distribution of each variable (or node) being as high as the number of parents (i.e. incoming arrows) pertinent to any variable. The final qualitative structure of the OOBN capable of mixing all the inputs and computing the expected overall progress in given in Fig. 9a: the three sub-networks discussed above give as outputs the single work progress, which is passed through the OOBN in Fig. 9a to the sub-network in Fig. 9-b, where the overall work progress is then computed as a weighted input from each of the sub-networks.

![Fig. 9. Qualitative structure of the overall work progress network (a) and sub-network for the computation of the work progress (b).](image)

Demonstrations

In this paragraph it is shown that the three sub-networks developed in the previous sub-section are able to model the processes under analysis. To this aim the networks have been used in the running modes and their inferences compared to the dataset. Fig. 10 shows how validation was performed: the variables on the left with red rows are those ones where evidences have been inserted, that is to say the state of the variables have been observed and fixed in the networks.

![Fig. 10. One of the validation cases for the sub-network relative to the excavation phase.](image)

Then the network performs inferences on the future states (time slice no. 3) and gives back the intervals depicted in Fig. 10, which are in accordance with the dataset. In Fig. 11a and 11b two other validation cases for the same sub-network are shown. It came out that the three sub-networks are capable of repre-
sented the process and restituting the non-linear relationships holding between the variables and regarding the work progress on the considered construction site.

Fig. 11. Two validations where estimations by the sub-network have been compared to the database.

CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper we have faced the problem of real-time work progress estimation. One of the difficulties lays in the need to decompose the tasks into sub-tasks and find out causal relationships among the involved variables so the whole progress may be estimated. In the case of construction sites there is no linear dependence (or functional relationship) between the resources employed at every hour and the work progress. So it was necessary to work out Bayesian networks representing second-order Markovian processes, whose causal relationships have been modeled through the EM learning algorithm, based on the use of Dirichlet probability functions. As it was demonstrated, the relative sub-networks well represent the several processes as probabilistic inferences are within the observations recorded in the dataset. Finally the qualitative structure of the overall network, working out the progress estimation has been proposed. Future steps will be relative to validations of the overall network and inferences performed with respect to tasks spanning longer time periods.

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References

Engaging isolated seniors and reducing caregiver burden

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Purpose The purpose of this project is to demonstrate the market viability of Mon Ami™ technology to support and maintain the elderly population living independently in the community, ensuring both social engagement and security for the individual and their family caregivers. It should also improve job performance and increase effective contact with seniors in a healthcare setting. It may provide a cost-effective tool to close the gap between what is provided formally, and what seniors and family caregivers require. Measuring the relationship between the user and the care unit presents as an essential issue in both preference towards the care unit and purchase.

Method We used an anti-oppressive, structuralist approach with a parallel (QUAN+QUAL and QUAL+QUAN) equivalent status design. Themes will emerge from the data collected rather than a priori. From CHATS (Community & Home Assistance to Seniors, a municipally funded seniors’ support service) 14 independently living participants were recruited, aged 60-95, and were engaged over a three-month period. Recruitment, training and implementation of the Mon Ami™ service was monitored and assessed by four student research assistants from Seneca College using structured quantitative forms and reflective qualitative interviews with open-ended questions focused on: ease of use of the technology for seniors, feedback from users to improve the unit’s overall system and function, and the optimum target market for sales of this product. Due to the limits of project time and funding, no internal validity could be established; however, a standard Quality of Life form was used as the baseline and terminal measure which had internal validity within the form itself.

Results & Discussion The Mon Ami™ technology may reduce the caregiver burden for seniors from 66 to 70 years old. Seniors (i) build relationships in an effort to maintain meaning of life, and to stabilize an ever-changing personal world, (ii) are naturally curious about the world and enthusiastic about the process of learning new things, and (iii) want to be connecting to the social world in a meaningful and purposeful way. The company needs to hire additional skilled employees in marketing and distribution and social service worker with gerontological expertise to provide training for seniors, and engage community funding partners such as the LHINs (Local Health Integration Network) in subsidizing and purchasing these units for low-income seniors.

Keywords: gerotechnology, electronic companion, aging, caregivers, ambient assistive living

INTRODUCTION The research that follows was an effort to evaluate an “electronic companion” entitled Mon Ami™, which is intended to be an “easy to use innovative product that allows caregivers, friends and family to look after and assist people in their care both locally and remotely.” Mon Ami™ was intended to facilitate the independent living of seniors and to bring structure to daily life, thereby enhancing their quality of life. It comprises a variety of services and features intended to enable easy communication with family and friends. Examples of these features are: email and video chats, notification of caregivers if action is required, and provision of reminders to seniors for such things as medications, appointments, events, etc. The unit is also capable of activating and deactivating electronic devices such as lights and stove elements. It can attach any electronic device which measures sugar levels, heart rates or additional medical equipment that has a USB attachment. The information in Mon Ami can be accessed by friends, family and professional caregivers, and the seniors themselves. It uses a touch screen mechanism and is internet based.

The research reported on was conducted on a group of 14 seniors aged 60-92yrs in conjunction with Seneca College’s Social Service Worker’s Gerontology (SSWG) Dept, Tertec Enterprises (industry partner), Community Home Assistance and Transportation Services for Seniors (CHATS). The project was funded by the Federal Economic Development Agency for Southern Ontario, Canada. Participating seniors were members of and recruited by CHATS. Participating seniors living independently in a non-institutional community setting with strong cognitive
abilities and some compromised physical functioning i.e. vision or hearing impaired, mild cognitive impairment, concurrent diseases etc. The goal of the process was to determine the marketability and viability of Mon AmiTM.

The research project was designed and supervised by SSWG faculty and carried out by 3 SSWG students and one Windsor University MSW student, research assistants (RAs). The research team noted that the seniors varied in their cognitive skills (memory, concentration etc), their familiarity with computers and the internet, and their willingness and ability to acquire new skills. The seniors’ responses to the electronic companion were measured quantitatively and qualitatively over an 11 week period. The researchers were interested in how easily and effectively the seniors could be trained to use Mon AmiTM. They were also interested in the barriers and problems that arose in training, learning, and using the software, the reactions of the seniors, their impressions of the “usefulness” of the Mon Ami, and the effectiveness of using Mon AmiTM in enhancing the day-to-day lives of the participants.

Researchers conducted three training sessions lasting one hour each session over the first 5 weeks of the project. In addition, 24 hour, 7 day a week online support was provided. Variables recorded by the researchers included: speed and ease of learning, frustration levels, retention of learned material. We also noted the degree to which participants independently explored the features of Mon AmiTM that had not been specifically taught. The data gathered included baseline, midline and final quantitative and qualitative evaluations, which allowed us to compare the initial status of the participants with post training results with the use of Mon AmiTM.

**Research methodology and data analysis**

The methodology employed is a “mixed methodological,” gathering both qualitative and quantitative data. We used a parallel (quan+qual and qual+quan) equivalent status design, where qualitative and quantitative data are collected at the same time and analysed in a complimentary manner. This pilot project is more of an exploratory investigation rather than a confirmatory investigation. In this approach, themes emerged from the data collected rather than a priori, consistent with the design model and contextual framework discussed. Data were collected on a 24 hour 7 days per week basis for any Mon AmiTM service activated i.e. email, music, alerts etc. We also administered a consumer satisfaction survey and a second ‘reflections’ questionnaire at the end of the data collection process.

Our findings were informative and sometimes surprising. We discovered that our participants enjoyed the social aspects of Mon AmiTM. They particularly liked video chats and used them extensively with their family and friends throughout the world, although they did not use Mon AmiTM as much to interact with their caregivers as we had expected and still preferred to see their caregivers on-site. On the other hand, we found that caregivers used Mon AmiTM extensively to communicate with these seniors for such issues as medication administration, activities of daily living, cues and prompting for dressing, bathing, medication and eating, checking-in with participants for updates on their well-being, and arranging remotely for appointments, transportation and food deliveries. We were pleasantly surprised to discover that areas of personal well-being, such as exercise, nutrition, information about new technology, good mental health, were considered very important by most participating seniors.

Because we gathered data at different stages of the 11 week project, we were able to compare changes in a number of variables across that time span. We found that the rate of improvement of participants’ skills depended upon a number of interrelated factors, for example, those who had computer and internet familiarity improved their skills at a far greater pace than those with less familiarity. Similarly, those from a higher socioeconomic status and or higher educational backgrounds, improved their learning of the unit more than others. The original report provides definitions and a preliminary language of subcategories in an attempt to discuss learner abilities when referring to gerotechnology such as: innovators, early adaptors, late majority adaptors, laggards, naive users and experts. While the early definitions created and adapted here are crude they provide a common lexicon with which to speak.

From the qualitative data three themes emerged to dispel ageist myths that continue to be perpetuated in a youth-philia society: 1. Seniors build relationships in an effort to maintain meaning and stabilise an ever-changing personal world. 2. Seniors are naturally curious about the world and enthusiastic about the process of learning new technologies. 3. Seniors of all cultures, all ages, all levels of education and economic brackets want to be connecting to the social world in a meaningful and purposeful way. These themes emerged through a process of chunking text into small bytes and identifying patterns of word usage such as, “play”, “interactive”, “easy”, “useful” and phrases like; “I enjoyed the music”, “loved the video chat”, “streaming Indian videos from back home was wonderful” etc. We also used the RAs observations of behaviours such as, increasing desire for them to stay and train participants on more...
features, stories participants shared regarding increased social access with Mon Ami™ which matched the quantitative data we collected over the 11 week period.

Though these observations comprise general trends and, because of the small number of subjects, did not quite reach statistical significance, one large and statistically significant finding was that seniors aged 66-70 expressed extremely high satisfaction with Mon Ami™, and this level of satisfaction decreased with increasing age. To our surprise those in the 60-66 age group reported less satisfaction than their slightly older counterparts, reporting that they were “too young” to benefit from the features of Mon Ami™:

Fig 1. Overall Satisfaction with Mon Ami™, F=5.74, p=0.19, seniors aged 66-70 most satisfaction of unit

Table 1. Feedback Table of Services Available on the Mon Ami™ Unit

<table>
<thead>
<tr>
<th>Service</th>
<th>Usage and reported experience</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Assist</td>
<td>Half n/a; half satisfied</td>
<td>See qualitative for details</td>
</tr>
<tr>
<td>Date</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Time</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Attempts</td>
<td>No interest</td>
<td>Low priority</td>
</tr>
<tr>
<td>Quick Timer</td>
<td>No interest</td>
<td>Low priority</td>
</tr>
<tr>
<td>Info Icon</td>
<td>Mixed between satisfied and unsatisfied</td>
<td>See qualitative data for details</td>
</tr>
<tr>
<td>Trail</td>
<td>Half n/a; half satisfied</td>
<td>See qualitative data</td>
</tr>
<tr>
<td>Home Icon</td>
<td>Most very satisfied</td>
<td>Medium priority</td>
</tr>
<tr>
<td>Next/Previous</td>
<td>Mixed results</td>
<td>See qualitative</td>
</tr>
<tr>
<td>Volume</td>
<td>Half n/a or unsat; half sat</td>
<td>See qualitative</td>
</tr>
<tr>
<td>Recordings 1</td>
<td>popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Recordings 2</td>
<td>popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Recordings 3</td>
<td>popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Calendar</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Photo</td>
<td>popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Reminders</td>
<td>popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Caregiver Reporting</td>
<td>Not used except with one caregiver</td>
<td>Unable to assess</td>
</tr>
<tr>
<td>Prompt</td>
<td>Popular with those who used it</td>
<td>Unable to assess adequately</td>
</tr>
<tr>
<td>Files</td>
<td>Not popular, many didn’t try it</td>
<td>Unable to assess adequately</td>
</tr>
<tr>
<td>Routines</td>
<td>Not used</td>
<td>Unable to assess</td>
</tr>
<tr>
<td>Music</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Books</td>
<td>Mixed satisfied and unsat</td>
<td>Medium priority see qual data</td>
</tr>
<tr>
<td>Radio</td>
<td>Mostly satisfied, some not</td>
<td>Medium priority</td>
</tr>
<tr>
<td>Games</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Jokes and Inspiration</td>
<td>Mixed reports</td>
<td>Medium to low priority</td>
</tr>
<tr>
<td>Movies</td>
<td>Not popular, not used</td>
<td>Low priority</td>
</tr>
<tr>
<td>Email</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Videochat</td>
<td>Very popular with those trained on it</td>
<td>High priority</td>
</tr>
<tr>
<td>Import Files</td>
<td>Mixed reports</td>
<td>Medium priority</td>
</tr>
<tr>
<td>Web Link</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
</tbody>
</table>

We found the results of our study were highly encouraging, but because of the small number of study participants and other difficulties encountered, the study requires replication. Difficulties encountered include:

- Early exits due to seasonal travel and illness
- Inability to measure professional caregivers responses to the unit due to funding and time constraints
- Resistance to new technology by “laggards”
- Variable cognitive abilities and functioning in learning new information and skills
- Response to avatar/equipment costs for seniors
- Adequate training of students research assistants
- Portability of electronic equipment for seniors
- Barriers for individuals who are significantly visually impaired or hearing impaired

RECOMMENDATIONS AND NEXT STEPS

Our recommendations fall into 4 categories: technical and unit features, target marketing, sales, replication and extension of our study. Among the technical and unit features recommendations are provided in the tables below.
Table 2. Frequency of Services Used Over the 11 week period of the project

<table>
<thead>
<tr>
<th>Service</th>
<th>Prior to Homework</th>
<th>After homework</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caregiver Report</td>
<td>Not used</td>
<td>n/a</td>
<td>More study with caregiver market needed</td>
</tr>
<tr>
<td>Inspiration</td>
<td>Not used</td>
<td>Rarely used</td>
<td>remove</td>
</tr>
<tr>
<td>Jokes</td>
<td>Not used</td>
<td>Rarely used</td>
<td>remove</td>
</tr>
<tr>
<td>File</td>
<td>Not used</td>
<td>Attempted rarely</td>
<td>Low priority</td>
</tr>
<tr>
<td>Books</td>
<td>Not used</td>
<td>Rarely used</td>
<td>remove</td>
</tr>
<tr>
<td>Music</td>
<td>Used frequently</td>
<td>Very popular</td>
<td>High priority</td>
</tr>
<tr>
<td>Video Chat</td>
<td>Used only by I-In users</td>
<td>Very popular where introduced with all user types</td>
<td>High priority; intergenerational and social feature</td>
</tr>
<tr>
<td>Calendar</td>
<td>Not used</td>
<td>Only the caregiver used it +++; participants low usage</td>
<td>More study on caregivers’ use</td>
</tr>
<tr>
<td>Prompt Recorder</td>
<td>Not used</td>
<td>Rarely used</td>
<td>More study with caregiver market needed</td>
</tr>
<tr>
<td>Email</td>
<td>Used frequently</td>
<td>Very popular</td>
<td>High priority; intergenerational feature</td>
</tr>
<tr>
<td>Games</td>
<td>Used frequently</td>
<td>Very popular, most heavily used service with weblinks</td>
<td>High priority; games must be appropriate and challenging; an intergenerational feature</td>
</tr>
<tr>
<td>Web links</td>
<td>Used by I-In and EAs</td>
<td>Very popular, most heavily used service with Games</td>
<td>More variety requested and training on uploading preferred sites to stream news and entertainment in culturally preferred languages</td>
</tr>
<tr>
<td>Radio</td>
<td>Not used</td>
<td>Moderate interest</td>
<td>Training required to upload users preferred stations</td>
</tr>
<tr>
<td>Photos</td>
<td>Not used</td>
<td>Most popular with L-Ns</td>
<td>This is an intergenerational feature and should be marketed this way</td>
</tr>
<tr>
<td>Reminders</td>
<td>Not used</td>
<td>Used moderately by all; heavily with caregivers in multigenerational households</td>
<td>A feature that probably requires more 1:1 training time with seniors and caregivers</td>
</tr>
<tr>
<td>Recordings</td>
<td>Not used</td>
<td>Used moderately as a result of RA requests and homework challenges</td>
<td>Unless prompted to use this feature by RAs or a caregiver not generally used though potential use as an intergenerational tool could see a market</td>
</tr>
<tr>
<td>Routines</td>
<td>Tried by caregivers and I-Ins</td>
<td>Used mostly by I-Ins, EAs and caregivers of participants</td>
<td>Market for caregivers use ties into caregiver reporting and prompting features; could be used as a multigenerational household tool</td>
</tr>
</tbody>
</table>

It was noted that the present Avatar, “Amber,” was met with mixed reviews by seniors. Males tended to enjoy her while females’ responses ranged from disinterest to offense. Therefore, a strong recommendation to provide the user with options to create and control their own Avatar was suggested by many of the participants. Having the avatar greet or prompt and cue the user would likely establish the relationship between unit and user at a quicker rate according to the qualitative data. One of the first observations we found was that the Mon Ami™ needs to be simplified. For example, there were too many icons, too many choices, too many steps for the seniors to learn and use Mon Ami™ optimally. We would recommend that someone start with a basic feature package and several training sessions limited to one hour each visit. Once learned, the user could purchase or utilize additional features as desired. We learned that a hard copy manual would be crucial as a reference guide. Seniors also wanted to take the unit with them when travelling or in hospital, and so a portable unit in addition to the current standing unit is recommended.

Target Market recommendations
There appear to be two target market groups. The first group appears to be isolated seniors with post-secondary education and a healthy pension/income between the ages of 60-70 who also have either some comfort with using computers or a higher level of expertise. Laggard learners will eventually learn the unit but, it was noted by RA observations, only if another stronger user is present, regular practice and use are undertaken, and they are provided with a greater level of on-site support on a more regular and consistent basis. It was noted by the RA observations that having the same support person come in to the home was crucial to this cohort. Seniors do not like a sequence of strangers entering their home but, always welcome a familiar and friendly face. The second market group appears to be the family caregiver. It was noted that caregivers who engaged in the project with their loved ones were using the unit daily and sometimes frequently throughout the day. Ultimately, the caregivers were the purchasers of the units during this study. To date, three units were purchased.

Sales Recommendations
We found that all seniors, even those in higher in-
come brackets, were greatly concerned with their financial situation. As a result there will likely be resistance to acquiring the necessary equipment without leasing options or subsidies. Different jurisdictions may have different subsidies available.

If Tertec were able to create an infrastructure where a Mon Ami™ “community” existed and Mon Ami™ users could chat virtually, arrange to meet socially at local community centres for seniors where workshops on learning more about Mon Ami™ and social activities were involved there would be a further level of commitment to the concept and units. Mon Ami™ Book clubs, Movie Nights, Chat sites, Date sites, Discussion and Learning Centres, Caregiver Support sites, and Travel groups may provide a strong infrastructure to stabilize the sales of the units and monthly rental of the portal and support.

This is a legacy tool which has the potential of being passed on from one senior to the next which each user developing an more intuitive relationship with the unit so that as they may deteriorate, the memory paths for using the unit are slower to degrade. This would maintain seniors in their home longer and reduce the stress that caregivers experience which drives them to demand more from the system which has insufficient financial resources to support them.

Extension of Study
Further research will be able to investigate at a number of potentially important variables we were unable to address within the constraints current pilot project. These include, evaluating Mon Ami with the population of cognitively impaired seniors, seniors in institutional settings, and professional caregivers such as, doctors, nurses, social workers, case managers and personal care workers etc. Further research should also employ larger numbers of subjects over a longer period of time to document their learning characteristics in order to determine whether there will be a change in the shape of the learning curve.

References
1. D'Silva, T., Personal communication, September 2011.
3. ibid
4. Grammer, C., modified version of several consumer's satisfaction surveys established in marketing products, 2011.
5. Grammer, C., and Gardner, C., developed a training tracking feedback survey and a reflections survey for the project, 2011.
Site layout optimization for caisson structure fabrication

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2 Civil Engineering Center, Marine and Port Team, SAMSUNG C&T Corp., Seoul Korea
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Purpose As the volume of international trade increased, the needs for large concrete caisson breakwaters, which can accommodate the bigger vessels, increased accordingly. However, due to the size of the caissons, the constructions of large-scale maritime infrastructures often face challenges about how to manage the construction site, improve the construction processes, and enhance productivity. Method This paper presents a methodology to optimize the caisson structure fabrication process by controlling the locations of construction equipment and prefabrication facilities using genetic algorithm (GA), coupled with the functions of a Delmia-platform. First, a virtual construction site layout is established with a set of required facilities and equipment on the Delmia-platform based on the spatial information of the construction site. Site layout constraints and requirements are then determined to properly reflect the nature and conditions of the projects. Lastly, a genetic algorithm is employed to find out the optimal construction site layout for the construction processes. Results & Discussion The proposed GA-based methodology is expected to assist construction engineers in determining optimized construction site layout for caisson structure prefabrication in the early project phase and further identifying the potential risks of projects.

Keywords: information technology, caisson, genetic algorithm, optimization, site layout

INTRODUCTION
A breakwater is one of the essential structures of a harbor that reduce the intense wave action in in-shore water. To provide a safe harborage area for vessels, a breakwater should be designed to absorb the huge energy of the waves. A breakwater generally consists of large pieces of mass concrete components such as caisson structures which are produced by the following steps: 1) fabrication of base plate; 2) fabrication of caisson wall; 3) concrete curving. These steps are conducted in three different places to handle large amount of construction materials and equipment for improved productivity of the caisson fabrication processes.

Defining construction site layout is important task, because it has significant impacts on productivity of construction projects. For instance, construction time and cost can be increased due to the inappropriate location of facilities and other construction resources. In case of large and complex construction projects such as harbor construction projects, the negative impact of improper construction site layout tends to become stronger. The construction of large-scale maritime infrastructure is challenging due to the large-scale of caisson structures and limited space for the caisson structure fabrication factory in the construction site. A methodology is required to optimize site layout of the caisson structure fabrication for improved productivity of harbor construction projects.

Numerous studies have been conducted to develop methodologies for construction site layout optimization. Yeh 1 utilized an annealed neural network to generate construction-site layout alternatives. Li and Love 2 developed a genetic algorithm (GA)-based site layout optimization method to deduce optimal location for site facilities. Hegazy and Elbeltagi 3 developed a GA-based site layout planning model which is called “EVOSITE” to search for the optimum site layout. Azadivar and Wang 4 developed a facility layout optimization method using simulation and GA. Osman et al. 5 presented an automated hybrid system for layout planning of construction sites using a computer-aided design (CAD) and GA. Al-Hussein et al. 6 developed optimization algorithm for selecting and locating mobile cranes on a construction site. Khalafallah and El-Rayes 7 proposed a site optimization model to minimize hazard of wildlife attractants using a multi-objective GA. Zhang and Wang 8 suggested a particle swarm optimization (PSO)-based methodology to solve construction site unequal-area layout problems. Easa and Hossain 9 developed a noble mathematical optimization model for construction site layout using a concept of resource leveling. El-Rayes and Said 10 proposed an approximate dynamic programming model to identify global optimal dynamic site layout plans. These previous studies showed that application of optimization algorithm to construction site layout problems could improve construction productivities. In particular, GA based
optimization approach has advantages in identifying global optima by avoiding falling into local optima. This study utilized GA to identify optimized site layout for caisson structure fabrication processes.

The objective of this study was to develop a methodology to optimize the caisson structure fabrication process by determining the locations of construction equipment and prefabrication facilities using GA, coupled with the functions of Delmia platform. The following section provides a schematic idea about how to simulate optimal processes of construction project on Delmia platform. Then, the methodology of optimizing construction site layout using GA is presented using an illustrative example. Lastly conclusions and suggestions are followed.

**Construction Process Simulation**

Figure 1 shows a construction process simulation conducted on the Delmia platform to identify optimized construction processes of the project. This computer process simulation provides the detailed time and schedule information for the GA model development. For the model development, the processes of caisson structure fabrication and associated activities such as crane operation are first modeled. Resource usage and traveling frequencies between locations are then deduced by simulating and evaluating the construction process. Using the probability density functions of each activity, construction time and traveling frequencies are calculated on the computer simulation platform.

**GA-Based Construction Site Optimization**

**Site layout definition**

In this study, the construction site layout optimization is focused on how to properly allocate construction resources on predefined locations in construction site. Fig. 2 shows the predefined locations on the construction site. The predefined locations are represented as rectangles and the area of each rectangle is the same.

The objective function of optimizing site layout is to minimize the total traveling distance between locations (Li and Love, 1998). The total traveling distance (TTD) is defined as eq. (1).

$$TTD = \sum_{i=1}^{n} \sum_{x=1}^{n} \sum_{y=1}^{n} l_{xi} f_{xi} d_{ij}$$  \hspace{1cm} (1)

where \( n \) = number of facility locations, \( l \) = location matrix variables, \( f \) = traveling frequencies, \( d \) = distance between centers of two locations.

In this study, 9 facilities are defined as follows: 1) Steel plate storage; 2) Concrete mold storage; 3) Steel rod storage; 4) Concrete curing place; 5) Fabrication factory of caisson wall; 6) Prefabrication factory of base plate; 7) Steel rod factory; 8) Crane 1; and 9) Crane 2.

**Site layout optimization using GA**

The Genetic Algorithms (GA), proposed by Holland, are heuristic search and optimization techniques that mimics the natural selection and biological evolutionary process. Unlike other optimization algorithms, GA has the capability of identifying global optima without falling into local optima. The GA model randomly searches for globally optimal solution which provides best fitness for objective function. In GA, a solution is represented as linear string called chromosome. A generation consisting of surviving individuals and new offspring is produced through reproduction mechanisms such as crossover, mutation, and selection of their parent’s chromosomes.

The location of facilities can be represented as a string form, as shown in Table 1 (Li and Love, 1998). The position of each cell represents a facility location. For example, Table 2 indicates that facility 3 is location 2 in Fig. 2. The travel frequencies per day between facilities and the distances between the nine locations are defined as listed in Table 2 and Table 3, respectively.
Table 1. String layout representation

<table>
<thead>
<tr>
<th>Facility</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2. Traveling frequencies between two locations

<table>
<thead>
<tr>
<th>Location</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
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<td>2</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>4</td>
<td>12</td>
<td>9</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>0</td>
<td>20</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>20</td>
<td>0</td>
<td>30</td>
<td>4</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
<td>12</td>
<td>7</td>
<td>30</td>
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<td>5</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>7</td>
<td>6</td>
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<tr>
<td>8</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>1</td>
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<td>7</td>
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<td>5</td>
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<td>3</td>
<td>15</td>
<td>6</td>
<td>9</td>
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</table>

Table 3. Distance between two locations (m)

<table>
<thead>
<tr>
<th>Location</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>8</th>
<th>9</th>
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<td>25</td>
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<td>47</td>
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<td>35</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>0</td>
<td>10</td>
<td>18</td>
<td>25</td>
<td>27</td>
<td>32</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>10</td>
<td>0</td>
<td>8</td>
<td>15</td>
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<td>22</td>
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<td>52</td>
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<td>4</td>
<td>33</td>
<td>18</td>
<td>8</td>
<td>0</td>
<td>7</td>
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<td>14</td>
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<td>15</td>
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<tr>
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<td>47</td>
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<td>14</td>
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<td>8</td>
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<td>24</td>
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<tr>
<td>9</td>
<td>35</td>
<td>50</td>
<td>52</td>
<td>44</td>
<td>37</td>
<td>35</td>
<td>30</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Best objective function values

<table>
<thead>
<tr>
<th>Population size</th>
<th>Generation</th>
<th>Mean (m)</th>
<th>Best fitness value (TTD)(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>100</td>
<td>1320.76</td>
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<td>2</td>
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<td>100</td>
<td>890.48</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>100</td>
<td>778.09</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>100</td>
<td>579.46</td>
</tr>
<tr>
<td>5</td>
<td>125</td>
<td>100</td>
<td>477.23</td>
</tr>
</tbody>
</table>

GA results

To deduce optimal site layout solutions, the GA analysis was executed on a MATLAB platform. In this study, five levels of population sizes were chosen to investigate effects of population size on the performance of the GA system. Experiments with difference population sizes (25, 50, 75, 100, and 125) were conducted under the probability value of crossover at 0.5 and the probability value of mutation at 0.01. As shown in Figs. 3 – 7, the GA system performed better when the population sizes are becoming bigger.
The result of the population size 125 presented the lowest total traveling distance and the best fitness value. The optimal objective function value – minimization of total traveling distance – was 369 m. The optimal site layout solution is presented in Table 4.

Table 4. Optimal construction site layout

<table>
<thead>
<tr>
<th>Facility</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
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<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

CONCLUSIONS AND RECOMMENDATIONS

This paper presented a methodology to optimize the caisson structure fabrication by determining the locations of construction equipment and prefabrication facilities. The proposed approach integrated computer simulation process and GA system for deducing optimal construction site layout. The simulation model for the construction projects enabled construction managers to effectively analyze and estimate process time and traveling frequency. The result of the process simulation provided reasonable input variables for developing the GA system.

Overall, the proposed GA-based methodology is expected to assist construction engineers in determining optimized construction site layout for caisson structure fabrication in early project phase. However, further study is required to improve the model, because the proposed model does not completely reflect the nature and conditions of construction site. Not only total traveling distance, but also interrelationship between facilities should be considered to improve the accuracy of the proposed model.

ACKNOWLEDGMENTS

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REFERENCES

Developing the ‘mStick’ concept: experiences and impacts

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Purpose The small-scale pilot study focuses on the memory and reminiscence stick (mStick) concept. It is a biographical memory store; personal documents, like family photographs, texts, audio and video clips, as well as materials linked to the owner’s hobbies and interests, are stored on a USB stick. The stick is a concept with a background philosophy focusing on reminiscence; the essence is not the technology itself, and future platforms may well be different. The stick concept provides meaningful entertainment to independent elderly people and those living in residential care or long-term care and suffering from memory and communication problems. Narrative gerontology and reminiscence studies over the years have shown that memories and personal life stories are important resources in the later life.

Method Nine pilots were launched in Lahti Region, Finland in 2010 and 2011 to examine user experiences. The pilots have been investigated throughout their implementation to assess impacts and usability of the sticks. Qualitative data were collected in 2010-2011 by means of interviews (33 end-users, 29 workers/students), learning diaries, photographs, memos, and participatory observation diaries (about 200 pages and over 200 photos) in the process of co-creation of the innovative concept. In this study, experiences gained during the development of the mStick are analyzed with the help of ‘Gerontechnology’s Five Ways’: prevention, enhancement, compensation, care, and research.

Results & Discussion According to the results, the mStick prevents the world from becoming narrower, which easily follows, as health and functional abilities deteriorate. Reminiscence work enables people who are confined to bed to be connected to other places and times. The stick concept creates ‘generational intelligence’, an ability to put oneself in the position of age-others by increasing intergenerational interaction and transmitting family history to younger generations. It also acts as an assistive device for care workers who organize reminiscence sessions and alike. It helps to see patients as whole human beings and facilitates communication between them and care personnel – thus potentially renewing the care culture. The contribution of this study is to bring forth experiences of ‘hybrid care’, a combination of services and products. The results are encouraging, as they show that the mStick causes positive impacts at many levels. There seems to be potential for cultural change in care practices, highlighting the need for a biographical approach in care work.

Keywords: health & self-esteem, memory support, gerontechnology, quality of life

INTRODUCTION

Technological solutions designed for the elderly too often replace human work and human contacts. The stick technology, presented here, rather increases human interaction, empowers senior citizens and enriches the quality of care work.

The mStick that has been developed in a Finnish research and development project is a biographical memory store. Personal documents - like family photographs, texts, audio and video clips, as well as materials linked to the owner’s hobbies and interests - are stored on an ordinary USB stick. The stick can also contain non-personal material related, e.g., to local history. The stick provides meaningful entertainment to active elderly people living independently as well as to those living in residential care or long-term care and suffering e.g. from memory and communication problems1,2.

The philosophy behind the mStick concept is that a human being is a biographical creature, whose memory never disappears completely – let alone memories. Narrative gerontology and reminiscence studies have shown that memories and personal life stories are important resources in the later life. The mStick represents simple, user-driven, personalised technology that empowers rather than labels; it implies proactive and tailor-made rather than reactive and standardised solutions; and its focus is on quality of life rather than on health alone.

Material requirements in the stick system are modest. Novel technological inventions are not needed.
Ordinary USB sticks and similar gadgets function as devices for information storage. The development work is not locked into single technical solutions or methods of use; rather, ‘pluralism of artefacts’ and various usages are implemented. The emphasis is not on physical artefacts as such, but on know-how and ‘gerontological imagination’ related to them.

The message of gerontechnology is that ageing people should be actively involved in shaping the technology that affects their lives. Active participation of the end-user characterizes the stick construction, because designing this type of “biographical technology” is actually impossible without the knowledge that the end-user (or sometimes her/his relatives) brings forth.

REMINISCENCE AND THE BIOGRAPHICAL APPROACH

The philosophy behind the mStick is based on the ideas of life review and reminiscence research and on narrative gerontology. Age is seen as cumulative rather than cross-sectional. Memories and personal life stories are seen as important resources in later life: they help to achieve ego-integrity and a sense of coherence, a sense that one’s own life has a meaning and significance which, in turn, helps with acceptance of finitude.

According to a heuristic model of reminiscence, people have a capacity, perhaps even a need to retrieve, articulate and disseminate self-narratives. Memories can be seen as building blocks of these narratives. Triggers like photographs, sounds or smells are sometimes needed to initiate the reminiscence process.

Reminiscence may have a powerful influence on identity maintenance of older people. It has been used with different goals, including the stimulation of cognitive functioning in older people with dementia and improving life satisfaction, quality of life and meaning of life among elderly.

Frail older people can offer up a past, preferred identity that has significance and richness, in contrast to their current identity which may be weak and fragile due to the loss of functional capacities. Activities encouraging meaningful linkage of the past with the present are essential in order to provide a sense of continuity to an older person’s life course.

Studies have shown that sharing past and present lives through talk is a central aspect of building relationships between residents and care staff in residential care. Reminiscence is important for care receivers but also for care givers. It can lead to greater satisfaction with work, including more positive attitudes towards the clients. In addition, it may offer intergenerational benefits. Through transmitting family narratives to children and grandchildren, an older person can again demonstrate the significance of past events and memories.

Three types of reminiscence interventions have been distinguished in the literature: simple reminiscence, life review and life review therapy. Simple reminiscence, for example conversations about autobiographical memories or the use of personal recollections, has social functions; it stimulates social reminiscence and bonding and promotes positive feelings. Life review is more structured focusing on the integration of both positive and negative life events and helping, e.g., people with a mild psychological distress to restore a positive self-identity. Life review therapy is an intervention applied in a psychotherapeutic setting.

The mStick concept is mainly based on simple reminiscence with life review implications. However, the principal focus of the mStick is on its social implications: interaction and communication in different environments; between care receivers and caregiv ers, between customers and public authorities, and between people of different generations.

FIVE WAYS OF GERONTECHNOLOGY

Known as Gerontology’s Five Ways, gerontechnology offers five key approaches to assist elderly people in continuing to lead healthy, active lives: prevention, enhancement, compensation, care support and research.

Prevention refers primarily to the use of technology in early detection and prevention of illnesses, and in support of healthy life styles. Prevention includes monitoring of an older person’s health and well-being, and preventing problems from occurring through interventions such as those that improve nutrition, increase physical strength, and encourage healthy habits.

Enhancement alongside with satisfaction refers to technology that increases the potential for self-expression and education. Methods and devices are developed in order to reach a wider benefit from ageing people’s strengths at work, in leisure time, in learning and social interaction.

Compensation refers to methods, devices and products which compensate for age-related functional decline. This is the most developed approach so far; it applies technology to compensate for declining physical, perceptual and cognitive faculties through the use of assistive devices.
Care support aims to enhance the work of caregivers by means of developing products that facilitate the care of elderly people, e.g., ergonomically-designed equipment.

The fifth way of gerontechnology helps ageing people indirectly by supporting scientific and clinical research. Sometimes only the first four ways are listed, and research is not included as an approach.4,20

Through these five ways, technology can be used to prevent problems, enhance experiences, compensate for declining capabilities, assist caregivers and conduct research to improve the lives of elders. The mStick functions in all of these five roles.

**RESEARCH DESIGN AND METHOD**

The data for the study were collected in a research and development project called ‘Sticks – innovative approaches to ageing people’s health promotion and memory support’. In the joint project of University of Helsinki and Lappeenranta University of Technology, two concepts – the health stick (hStick) and the memory and reminiscence stick (mStick) – are being developed with a user-centred approach in multi-actor innovation processes and networks. The mStick – which is the topic of this study – is a concept with a background philosophy focusing on reminiscence, as described earlier. The essence is not the technology itself, and future platforms may well be different from USB sticks. The concept is being co-created with end-users, care workers, teachers and students of health care.

The mStick has been piloted in Lahti Region, Finland. Nine pilots in public and third sector organizations operating in the field of elderly care or citizen activity were launched in 2010 and 2011 to examine user experiences. With researchers and developers’ support, the pilot groups produced various kinds of mSticks with the aim of responding to the specific needs of the stick owners. The pilots have been investigated throughout their implementation to assess impacts and usability of the sticks. The research has been conducted with an explorative approach: the question is about the process of co-creation of the innovative concept and collective knowledge creation from different perspectives.

Qualitative data were collected in 2010-2011 by means of interviews (33 end-users, 29 students/workers in elderly care, both from management and employee positions), learning diaries, photographs, memos, and participatory observation diaries (about 200 pages and over 200 photos) in the process of co-creation of the innovative concept. The data were analyzed according to the principles of qualitative content analysis. Contents of the interviews and other data were categorized and classified according to the ‘Gerontechnology’s Five Ways’: prevention, enhancement, compensation, care, and research.

**RESULTS**

As concrete results of the piloting phase a rich spectrum of different mSticks were created, mirroring their creators, the pilot organizations and their customers. In addition to the contents of the sticks, which are naturally unique in each case, there were differences concerning, e.g., the target group, the technical platform, the structure and the actor network around the sticks. Table 1 summarizes the contents, outputs and participants of the nine pilot cases.

<table>
<thead>
<tr>
<th>Pilot no.</th>
<th>Aim/contents of the pilot case</th>
<th>Form/output of the pilot case</th>
<th>Participants in the pilot case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A personal mStick as a medium of communication to tell about the cultural and educational background of immigrants</td>
<td>Digital life stories (Windows Media File) Diplomas (translated and scanned into a digital form)</td>
<td>Group of highly educated immigrants + the group leader</td>
</tr>
<tr>
<td>2</td>
<td>A personal mStick for independently living elderly people</td>
<td>Photographs, written stories in a digital form</td>
<td>Three independently living elderly persons, their group leader and assistant</td>
</tr>
<tr>
<td>3</td>
<td>A personal mStick for customers of senior homes</td>
<td>Photographs, oral stories in a digital form</td>
<td>Four elderly persons, students of social and healthcare and their teacher, a service consultant</td>
</tr>
<tr>
<td>4</td>
<td>A collective mStick for a senior activity centre with a special theme: from sheep to wool, from wool to sweater</td>
<td>Photographs, oral stories in a digital form as well as concrete, touchable material (wool)</td>
<td>Customers in a senior activity centre and group leaders</td>
</tr>
<tr>
<td>5</td>
<td>A collectively compiled structure for a personal mStick for</td>
<td>Central contents and a structure for an mStick which were</td>
<td>A group of men with early stages of dementia and their group</td>
</tr>
</tbody>
</table>
The research results are reported in greater detail in the following, categorized according to gerontechnology’s five ways.

**The mStick as prevention and engagement**

According to the experiences gained in the pilots, the mStick causes positive effects on the quality of life by offering meaningful contents to life, increasing the feeling of coherence of life, facilitating social contacts and increasing appreciation, which all have a role in prevention of illnesses and social isolation.

The concrete experiences gained in the process of producing the materials for the mStick have shown that the mStick might help to prevent memory diseases. The simple process of selecting the photographs with an elderly person, to be stored on the stick may serve as a memory exercise in itself:

“Yes, it became a true memory exercise, when we went through these photos and tried to remember what happened and when.” (an elderly man who took part in the mStick pilot)

For a person with memory problems watching the photographs of relatives caused anguish at first, because she didn’t remember their names, but finally the effort was rewarded:

“I noticed her anguish when she didn’t remember who the man was in the picture […] but after we had circulated the same photo series four times, I guess – she remembered – ‘Hey, it is Pentti, wonderful, it’s Pentti!’” (a student who made an mStick with a woman with memory problems)

The process of making the mStick increased social contacts and human interaction. Some tentative observations were collected that indicate that this might contribute to delaying the progression of long-term illnesses, like the Parkinson’s disease.

**The mStick as enhancement and satisfaction**

Enhancement and satisfaction are related to the potential which the mStick has: as self-expression and in highlighting and utilizing the resources that elderly people possess.

According to the data, looking back to childhood memories has brought joy to life after widowhood. Older people have experienced both the reminiscence and the preserving of memories as meaningful entertainment which has brought novel contents to life.

“It has been fun to share memories with outsiders, as there have been some unusual incidents in my life.” (an elderly man who took part in the mStick pilot)

“Also my children have noticed that now this grandpa has got some new power.” (an elderly man who took part in the mStick pilot)

From the life review perspective, reminiscence may also function as part of a person’s identity work, helping to build a feeling of coherence in life:

“Writing the life story helps you find something that maybe indicates that the chosen direction has been a good choice and you can accept the decisions you have made.” (a woman taking part in an mStick pilot)

Memories are an important resource for an older person. ‘Living in the past’ should not be regarded as regression, but as a crucial part of human essence.

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|   |contents, outputs and participants of the mStick pilots. |
|---|---|---|---|
|6| A collective mStick about the history and activities of a handicraft group of seniors |Photographs, video clips, audio clips in a digital form |A group of seniors and their group leader |
|7| A personal mStick for customers of a senior activity centre |Written life stories, photographs, audio clips, other personally important documents in a digital form |Four seniors and their group leaders |
|8| A personal mStick for customers of senior residential services and a collective activity stick |Digital life stories (Windows Media File), photographs with texts, oral and written stories, personal biographical information in a semi-structured form |Four elderly persons (some of them with dementia), their near relatives, students of healthcare and their teachers, care personnel, a service manager |
|9| A personal mStick for patients with Parkinson’s disease |Digital material in various forms |Patients with Parkinson’s disease and their near relatives, a group leader |

Table 1.
as a biographical creature and as a way to build one’s identity. Nostalgia can be a reflexive, not necessarily regressive sentiment. Elderly people can perform meaningful ‘identity work’ or accomplish ‘mature imagination’ by reflecting their biographies. Identity work is an everlasting task for a human being, according to modern identity theories.

The stick functions in an important role in the empowerment of older people. Quite an enthusiasm has been prevailing in the development phase of the sticks, and this indicates that the sticks are one way of preventing older people from being left aside from the information society.

“I have noticed that the fear towards technology has already turned to curiosity.” (a service consultant in senior residential services)

The mStick offers opportunities for lifelong learning. Preserving the life story and other biographical documents into a digital form and utilizing opportunities offered by information technology (IT) have evoked a new kind of interest to learn computer skills among the elderly. Third sector educational organizations have taken an interest in the matter, too. There are plans to organize ‘Stick courses’ for seniors. In these courses, the aim will be to build illustrated digital life stories and simultaneously to learn IT skills in a personally meaningful way.

A very essential function of the mStick is that it increases intergenerational interaction and transmits the family history. Young people are not always eager to listen to old people’s stories, but through new technology they may well become interested in the lives and experiences of their older relatives. The stick can build a bridge between generations, as told by an over 80-year old lady, who recorded her greetings to her great-grandchildren:

“So now this whole life of mine is there on one tape, and then at the end, I gave my regards to that fourth generation – of them, tomorrow, the fifth of the fourth generation turns one year old. So this is left for them, the bigger ones remember me all right, but these little ones will not remember me anymore, so they will see from photos what the great-grandmother was like and she even gave her regards to them – so that’s a nice thought.” (a woman taking part in an mStick pilot)

The mStick creates ‘generational intelligence’, an ability to put oneself in the position of age-others. It offers a possibility to collect generational memories. The society is changing rapidly, and, e.g., stories concerning the everyday rural life a few decades ago are regarded as very important.

“The children of today have no idea about how the life was in that time.” (a man taking part in the mStick pilot)

The mStick as compensation and assistance

The mStick compensates weakening abilities from the social perspective. The mStick prevents the world from becoming narrower, which easily follows, as health and functional abilities deteriorate. Reminiscence work enables people who are confined to bed to be connected to other places and times. Reminiscence through the mStick also enriches social interaction by building bridges between people. People living in care institutions can acquire a status of a recognized individual, not only that of a patient, in the eyes of care personnel and other patients.

“This illness (dementia) makes you somehow more blank, and if at this stage the customer is ‘faceless’, there are many things that the nurse doesn’t understand. But if the customer has a face and a past, he or she is a person and can be regarded in the right way.” (the responsible nurse of a dementia unit)

The mStick may function as an instrument to express oneself and tell about one’s life and wishes, even if a person is not able to speak. Tools for this are being planned in a new pilot. The mStick also helps the communication of those who have memory problems, functioning as a memory support. A group of men suffering from early stages of dementia, together with their group leader, planned the contents of their mStick, with the aim of telling what things are important to them and what they wish when the disease progresses. They came up with the idea that the mStick might function as a kind of “mental testament” for people with incurable illnesses.

The mStick also offers an instrument to immigrants and other minorities, who have problems in getting heard in the society, for telling about their background and storing the official documents needed in the complex process of integration.

The mStick as care

The mStick is an example of ‘hybrid care’, where the core of the supply is a combination of service and product. Technology and the related services form an intertwined entity, where technology is an enabler of new opportunities for care services. The memory stick is ‘just’ a piece of technology, but it becomes part of a service act when it is loaded with biographical contents and utilized.

An important factor related to care support is that the
mStick does not replace but rather promotes and enriches human contacts and mutual communication. The role of the mStick is not replacement of human workforce in the care work, but rather enrichment of the work. The benefits are especially great if a person has communication problems which easily lead to misunderstanding.

“This is great – here you can really see that this person likes that the hair rollers are put into her hair after the sauna or shower. When you concretely see it, you’ll remember it better.”
(a nurse who was shown an mStick of an elderly woman)

The mStick enables care workers to see the patient as a holistic creature with a biography and a past. It facilitates communication between patients and the care personnel - if names of the relatives are saved on the photographs, for instance.

Televisions with USB ports are used as mStick platforms, if computers are not available or if they are felt to be aversive. A simple platform is a digital photo frame, which is rather cheap.

“If you think that this resident does not remember the names of relatives or mother or sisters, for example, so if the names have been recorded here, the care worker can utilize them – see, here is this ‘Elma’.”
(a student who made sticks with elderly customers in residential services)

“If she talks about her son Mikko who lives in Australia and is not keeping in touch... the care personnel does not have to wonder who is that son who comes up there all the time. He is not an illusion but he is real, her son Mikko.”
(a student who made sticks with elderly customers in residential services)

Even though ‘holistic care’ is desirable, the way in which the healthcare professionals often talk reveals that the ‘basic work’ consists only of the medical and practical treatments. The students of healthcare and their teachers in the pilots emphasized that “stick tailoring” and the related biographical approach as part of studies and curricula would be an important step towards a change in job descriptions and the care culture. The use of the mStick is a step towards holistic care, where a person is seen as an entity, not just a patient with certain illnesses. There seems to be potential for a cultural change in care practices, highlighting the need for a biographical approach in care work, where getting to know the customer more deeply is not felt as extra work but as an internal part of basic care. The mSticks are concrete tools for applying this kind of a holistic approach. A biographical approach may also raise social appreciation of elderly-care work.

One of the pilot organizations set the aim of making an mStick for every new resident:

“In this way we get to know something very essential about the resident. The life history is very important. It is related to the autonomy of the person, which is an essential part of the care work.”
(a service manager in third sector residential services)

The mStick can also act as a new kind of tool and service product for care workers organizing reminiscence sessions and other joint programmes, for instance in institutions for seniors. The sticks that are produced within one reminiscence group can be shared and used also in some other group, if appropriate. For instance, a group of seniors from an activity centre visited a sheep farm, and then participated in the whole process of producing a sweater from wool in the traditional way with several phases (dyeing, spinning, knitting...). Visits and conversations were videotaped. The video will be used in several senior activity centres as part of activity programmes and reminiscence sessions.

The mStick as research
The mStick is being developed with a strong connection to research. The impacts of the mStick are examined at many levels; the findings presented here have just ‘scratched the surface’. In the future, the mStick may, e.g., play a role in memory research. Its memory test and game applications can be based on personally relevant and meaningful material.

Table 2 summarizes examples of the impacts of the mStick according to Gerontechnology’s five ways.

<table>
<thead>
<tr>
<th>Way</th>
<th>Examples of the impacts of the mStick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention</td>
<td>Cognitive impacts: memory exercise</td>
</tr>
<tr>
<td>Enhancement</td>
<td>Increases intergenerational interaction, transmits the family history</td>
</tr>
<tr>
<td>Compensation</td>
<td>Enables people who are confined to bed to be connected to other places and times</td>
</tr>
<tr>
<td>Care</td>
<td>Helps to see patients as whole human beings; facilitates communication between patients and the care personnel</td>
</tr>
<tr>
<td>Research</td>
<td>Memory exercises and tests</td>
</tr>
</tbody>
</table>

Table 2. Impacts of the mStick analyzed with the help of Gerontechnology’s Five Ways.

CONCLUSION AND DISCUSSION
The experiences gained in pilots in the development process of the mStick have been encouraging. Many of the elderly people were first little suspicious about new technology and this kind of a working method,
but in the end, most of them got the feeling that it was more than worthwhile to ‘jump into the unknown’, and they expressed their thankfulness in many ways. Also the care workers regarded the mStick as a useful tool in their work and were willing to develop it further in order to implement and adapt it as permanent practice in their organizations.

Maybe the most important and valuable function of the mStick is the role of memories in social contacts: building bridges between generations and facilitating the communication in care contexts.

Some suspicions and barriers have naturally come along, too. Even though people like to tell about their lives, they may be a bit shy to tell about themselves – a typical Finnish feature perhaps. Thus, to begin is often the most difficult thing, but after one finds the courage to reminisce and has a receptive listener, new paths are found all the time. The next challenge, then, is to find a structure for parsing your biographical data.

Also technology-related problems have been met. Even though the mStick is rather simple as technology, its idea may be difficult to understand for persons not familiar with computers, and it may be confused with the internet, for example. The mStick, however, is easier to understand as compared to the alternative that the personal information were stored in the “cloud”.

The questions of when and how to make an mStick have to be pondered individually in different situations. For instance, for some persons, it may be inconvenient to do the reminiscence work when she or he is moving from home to a dementia unit, for instance, because the current life situation may be stressing and confusing. In this case, an option could be to use generalized reminiscence material instead of personal material. For some other persons, however, looking into the past may build integrative bridges in the phase of change.

The study showed that there is a need for a service which we like to call “stick tailoring”. Tailoring the mStick takes time, especially with people suffering from memory diseases. Some active seniors may be able to collect and store the material to the stick themselves, either independently or in courses and groups, but in most cases, some extra help is needed. The role of near relatives may be crucial here. Tailoring of sticks is a job that requires - not only IT and information-related skills but also - a humanistic approach, gerontological knowledge and social skills. When producing an mStick, a stick tailor interviews the ageing person and/or her/his near relatives concerning the owner’s interests, obtains family photos and other materials for scanning, and produces the prototype of the mStick – the contents of which are always possible to develop further and expand. Good experiences have been gained of having social and healthcare students as stick tailors; in the pilots they have found the work very inspiring and useful.

Tailoring of mSticks is also a question about job descriptions in elderly-care, and a possible shift towards a care culture where getting familiar with the customer and the biographical approach is an integral part of the care work.

So far, the experiences mainly concern the development phase of the mStick, choosing the material, producing and storing it on the stick. The concept itself is still under development, and results concerning, for instance, the long-term use of the mStick are still forthcoming.

References


Estimation with applications to dynamic status of an excavator without renovation

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Purpose Operators and drivers are easily exposed to danger by excavators is operating in dangerous places such as slopes, soft ground, building dismantling sites, distressed areas, and construction waste land-fills. For the safe use of conventional excavators as a tele-operated system without any renovation, feedback information of the boom, arm, and bucket cylinder should be estimated as a schematic of the excavator arms with the same of joint angles, respectively. There is a strong need for acquiring this information using the proposed sensor system and converting algorithm enabling each joint angle to be derive for a commercial excavator without any renovation and remodeling. Method This study provides kinematic and dynamic information of the excavator. The proposed sensing module, which derives joint angles set by IMU-sensors, is implemented in the excavator. Acquired and estimated data from the sensing module and true known value was compared through prototype demonstration. Results & Discussion Detachable sensor modules and robotic manipulators were installed in an excavator; a field test verified the feasibility of implementing the proposed estimation method.

Keywords: robotics, sensing mechanism, estimation, installation type tele-operated excavator

INTRODUCTION

The safety of the construction site and the quality and productivity of the construction industry can be improved by automating construction equipment. There are limits not only to operating construction equipment in dangerous places such as slopes, soft ground, building dismantling sites, distressed areas, and construction waste landfills, but also to working in these places, because operators can be exposed to dangerous environments (Fig. 1). Excavation and earthmoving equipment mostly operate in accident-prone areas. These areas normally have rollover, confinement, and fall or may be considered harmful work areas due to demolitions and sewage removals. The situations may be different from those using forklifts that are mainly used in manufacturing and distribution industry fields like factories and ports. Considering the aforementioned, it is inevitable that excavation and earthmoving systems should be developed to secure the safety of operators through unmanned and remote control systems. Therefore, it would be considered appropriate to develop the excavation and earthmoving systems to prevent accidents and damages that harm lives. A number of ways may be considered to reduce industrial disasters and death rates through automatized, unmanned, and remote-controlled systems.

Based on the earlier research work from the beginning of 1990s, implementation of an autonomous tele-operated excavator mainly focused on three parts: modelling, parameter identification and control strategy. Some studies have even introduced an estimation scheme of real-time soil parameters other than an understanding of the excavator. The subjects of the remote-controlled excavator on...
which this research focuses were utilized in trainings for excavation workers. These are achieved by adding and expanding the concepts on haptic and force feedback as well as the virtual reality concepts of the so-called ‘virtual excavator’ from mid-1990s to the beginning of 2000s4-7.

However, all of these subjects can be among the interruption factors that may not be useful in the actual excavation works. If the feel of touch is exercised for long hours, the operator does not only get fatigue but he is also exposed to the higher risk of musculoskeletal disorder due to his long-term exposure on vibration and impact. Therefore, the feel of touch is recommendable to be limited in use when the work is done in a short time, or when the underground pipes such as Hume concrete pipes should be avoided from destruction during excavation.

The development of cases actually shows that the majority of remote-controlled systems enable the work to be conducted within visible ranges (Fig. 2). These systems are commonly done with remote control enabled from the development stage. These systems are applied with the concept that the existing heavy equipment for excavation cannot be reused6-14.

Therefore, this research proposes a system that enables excavators to be unmanned and remote-controlled without remodeling, change, or transformation by applying attachable and separable mechanism and modules. Moreover, this research proposes the sensor concept to evaluate the status without processing remodeling or transformation the existing hydraulic drive excavation system by adopting the easy attachable and separable mechanism. The study verifies this proposal based on observed possibility and feasibility through the experiments.

**SYSTEM CONFIGURATION**

**Proposal of the tele-operated excavating system**
As mentioned, this research proposes a system that enables the existing excavation heavy equipment to be operated unmanned and remote-controlled without remodeling or transformation. The attachable and separable mechanism attached on the control stand and pedals in the excavator cabin is remote controllable, while the telecommunication between devices is composed to add various devices and assign functions using the CAN-BUS. The ZigBee is used to control the internal devices of the excavator from a remote distance. The RF frequency range used is 2.400 to 2.4835GHz and the data rate is 250 kbps. The line of sight communication was used to utilize the remote control, as it is a prototype test and the wireless communication regulation was established considering the operations of control system, characteristics of working environments, and communication distances in accordance with the general remote control methods which were reflected to the system. The basic construction of the system is as shown in the figure 3. The remote control system of existing excavator enables the work to be performed only within a visible distance; however, the system adapted the ZigBee wireless communication standard works theoretically at a further distance within 1.3km communication radius. If the force reflection devices, vibration transmissions, and sensors which could support human senses could be added further, more intelligent system using the existing excavator can be constructed.

As the composition of sensors is made to comprehend the status of outside and inside works and operations of the excavator, this thesis aims to propose a sensor that can comprehend instrumental or dynamic status of the excavator using the attachable and separable modules without change or transformation, and to verify its possibility.

**Concept design of sensor module**

The excavator can be assumed as a 3-DOF manipulator generating the boom, arm, and bucket movements. The status can be understood by measuring the degrees for each joint. This thesis proposes a sensor system to comprehend the instrumental and dynamic status of the attitude reference system (ARS) based excavator which consists of 3-axis acceleration sensors and 2-axis gyro sensor modules. The ARS sensor module mentioned in the above is a module that calculates the roll and pitch angles among six pieces of three-dimensional detail information (i.e., x, y, z, roll, pitch, and yaw) being mounted with a 32-bit ARM Cortex-M3 microprocessor. This controls all sensor interfaces besides the acceleration and gyro sensors, and obtains the roll-pitch angles by combining the values of each sensor.
Fig. 4. Proposal of the sensor module for deriving posture of the excavator using ARS using Kalman filters at this time. The module interfaces with outside through three kinds of interfaces (i.e., UART, I2C, and USB) after obtaining raw data, roll, and pitch angles of each sensor (Fig. 4). The ARS sensor modules are commonly used in measuring movements and inclinations of bipedal robots. The sensors are broadly applied in posture control of the unmanned aerial vehicles (UAVs) and dead reckoning of the vehicles. The sensors applied in this research use myARS-USB in generating each axis’ angle information of the excavator through which the sensors are expected to generate more intelligent excavation environment and supply the work environment information of the remote control workers.

The resolution of the sensor enables the measurement to be conducted every 0.01 deg. and its bandwidth is specified as 40 Hz.

STATUS ESTIMATION OF AN EXCAVATOR

Before the sensors were attached and the experiments were conducted to estimate angles of a commercial excavator, each link segments corresponded to the boom, arm, and bucket of the excavator. They were mapped the same way as No. 2, 3, and 5 axes of the manipulator to examine the possibility of sensors using 6-DOF serial manipulator in the laboratory. The details are shown in the Fig. 5 and Fig. 6.

EXPERIMENTS

Experimental set-up

The attachment positions of sensors are defined (see Fig. 7) and are considered the positions to represent each link segment assumed in the previous Fig. 6. Each joint angle can be assumed as the values to define the angles of the boom, arm, and bucket of the excavator. This can be achieved by analogizing the roll and pitch angle values of the ARS sensors explained earlier with each joint angle value. The angle estimation of the ARS sensor modules were performed in the range of from -180 deg. to 180 deg. and the data acquisition used NI c-Rio. Each sensor module (No. 1, 2, and 3) was all connected by the CAN-BUS method and the encoder value of the manipulator was connected in the serial method to motivate the start of test-run time in gen-
erating angles. In actual application to the excavator, the connections after the attachment of each ARS sensor will adapt wireless methods (such as the ZigBee or Bluetooth). It can adopt the CAN-BUS method to allow the possibilities for additional composition of other sensors other than the angle estimation sensors.

This experiment established and applied the DAQ sample time at 20 msec. This is characteristic of the excavator suitable for comparatively rough measurement. Considering 25 msec is set as the sample cycle of the ARS sensors, the cycle should be established not to cause information losses during data recovery and estimation in utilization in the real integrated control. The proper time should also be assigned for the operator to confirm and refer the angle information in the remote-controlled excavation work.

The experiment was conducted by comparing the actual angle values of the manipulator while driving the manipulator to conduct the dump and crowd processes from No. 2 through No. 9 processes after positioning the manipulator at No. 1 home position (Fig. 8). The values obtained from the angle calculation/estimation of the ARS sensors are proposed in this research. Each graph represents the results value of the joint No. 2, 3, and 5 of the manipulator, while No. 1 dot chain line displays the actual angle values estimated from the encoder of the manipula-
tor. The blue line the angle values calculated from the ARS sensors attached on the link segments.

**Experiment result**

No. 1 and 3 ARS sensors confirmed the upper/lowest limits of the angle ranges being shifted, while No. 2 ARS sensor showed the tendency of the angle variation concurrence and the upper/lowest limit ranges. These are considered phenomena because of the sensor attachments. Therefore, the ARS sensor concept for the angle value estimation in the actual excavator should remove the upper/lowest limit ranges in the angle estimation, and the additional considerations should be made on the instrumental conclusion method to compensate the errors in the angle value estimation. The problems such as the angle calculation values of No. 1 and 3 ARS sensor appeared in this experimental result can be compensated.

In addition, it was confirmed that data on the variation and tendency of the angle calculation values through the sensors ensure the real-time characteristics, which the remote control operator of the excavator cannot recognize considering the sample cycle, is set as 200 msec. It verified that this proposal of the sensors is proper and applicable to the actual excavator because the extended 10-time experiments with the daum and crowd confirmed no appearance of the sensor error accumulations and drift phenomena caused by the ARS sensors (Fig. 9).

**CONCLUSION AND FUTURE WORK**

This research proposes the concept of the remote-controlled excavator that can be operated at a remote distance without remodeling, transformation, or renovation on the existing excavators. The proposal includes a system using the easy attachable/separable mechanism, and the sensor information of the excavator of the work and invisible modules that can supply the operator the status ranges at a remote distance. The ARS sensor modules proposed in this research which conducts the angle estimation of the excavator is investigated through the experiment. The feasibility was verified by using the 6-DOF manipulator which can study the posture of the excavator, simulating the excavation work under the condition of restricting parts of degree of freedom of No. 1, 4, and 6 axis movement, and comparing the estimated values obtained from the motor encoder and the angle values calculated by the ARS sensors at that time.

The sensor error or drift phenomena due to long hour operation was not found in the experiment; however, error accumulations occurring in the measurements of the vibration systems such as the excavator and error occurrences caused by faulty installations of the sensor modules will be compensated through future studies. Thus, the research plans to construct an integral system that can support the excavation work in a remote distance and expect to compose a human-robot cooperation system by combining the logical ability and intelligence of human beings (see Fig. 10).

**Acknowledgement**

This work was supported by the Industrial Strategic technology development program (No.10040180, Development of remotely piloted and optionally manned excavating system using detachable robot manipulator without any conversion of conventional excavator) and the Industrial Foundation Technology Development Program supervised by the KEIT (No. 10040210, Development of the safe joint modules of 150Nm classes and force-torque/ joint torque sensors for the dual-arm robot) funded by the Ministry of Knowledge Economy (MKE, Korea).

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Introducing and applying a modified AHP (Analysis Hierarchy Process) to analyse productivity at the construction site.

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Purpose Improvement of on-site productivity has been a very important issue in the construction industry and construction companies struggle to overcome this problem. In Korea, a construction company considered adopting a newly developed construction tool from other countries. The company would like to measure productivity before and after adopting the tools. The objective of this study is to understand productivity analysis for selected advanced construction tools in the construction site where the tools were used. This study is aimed at valuation of productivity as a result of the application of the existing and advanced tools using analysis hierarchy process (AHP) which is a representative survey method.

Method For this study, several surveys were conducted to obtain from the managers’ and practitioners’ viewpoint. By analyzing this, a tool-guiding method was developed and a construction tool application was selected before buying or adopting these tools. AHP is useful for understanding the complex structures which combine the macro-view of manager and the micro-view of practitioner. So in this study we used the AHP and evaluated the productivity. Results & Discussion Through survey and pairwise comparison, we obtained information on the evaluation factors that the manager focused on. Also, the practitioner evaluation was derived from the survey on a maximum scale of 7 points. This way the existing and an adapted tool may be compared. Introducing and using the advanced tools, manager and practitioner succeeded in identifying priority factors.

Keywords: productivity, work-sampling, AHP (Analysis Hierarchy Process), construction tool

INTRODUCTION
Productivity is used as a tool to measure real production activities in all industrial areas. Productivity is defined as the ratio of input and output when products are manufactured for a certain period of time using a production system.

The construction industry is labor-intensive, its work is performed largely outside, a large number of businesses in the area engage in a project together; as a result, the industry has many factors to make it hard to evaluate its productivity. Therefore, application of the concept of productivity to the industry is not so simple; therefore labor productivity is commonly used.

Factors that influence on construction productivity are broadly divided into two. They are internal influence factors that may be controlled within a production system and external influence factors with the opposite concept. Enhancement in productivity is mainly achieved by improving internal influence factors.

Internal influence factors are divided into hard factors—product, technology, materials, energy, plant, and equipment—and soft factors—construction controls, work methods, people, organization, systems, and management style. Productivity is enhanced through the removal and improvement of inappropriate internal influence factors.

Fig. 1. Factors that Influence Productivity of the Construction Industry
High productivity in advanced countries’ construction sites were judged to result from efficient application of advanced construction tools to unit work. Here, advanced construction tools mean high-performance work tools, small equipment, or safety goods that have not been applied to sites in Korea but are in common use in advanced countries. Accordingly, this study introduced advanced construction tools for productivity enhancement through improvement in internal influence factors. Further, this study collected and analyzed opinions of managers and workers at construction sites using a questionnaire, aimed at a measure to select and utilize advanced construction tools.

**METHODOLOGY**

A comprehensive evaluation of advanced construction tools was made, with a structure of combining managers’ macroscopic insights and managers’ microscopic opinions. The questionnaire has two parts of calculating managers’ weight and evaluating workers’ degree of satisfaction. Analysis hierarchy process (AHP), one of multi-criteria decision making methods, was used for this purpose.

AHP is a technique presented by Thomas. L. Satty and one of decision support systems. This is widely used in multi-criteria decision making that includes both quantitative and qualitative elements; this method has enabled comprehensive evaluation and integration of quantitative and qualitative elements. AHP classifies decision making elements into goal, criteria, and alternatives, and structuralizes and systemizes such elements. In particular, one of the most significant characteristics of AHP is to provide hierarchy to a complicated problem and divide its factors into major factors and sub-factors, make a pairwise comparison of these factors, derive their weights, and prioritize them.

<table>
<thead>
<tr>
<th>Table 1. Pairwise Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
</tr>
<tr>
<td>A2</td>
</tr>
<tr>
<td>A4</td>
</tr>
<tr>
<td>A5</td>
</tr>
</tbody>
</table>

Under this pairwise comparison, the value from comparison between the same items is 1.0 and a reverse comparison results in a reciprocal number. Further, decision making is made by verifying consistency of the calculated weights. Thanks to such advantages, AHP is one of the most widely used techniques among exiting decision making methods. This study modified and applied using AHP. The questionnaire for the calculation of managers’ weights aimed at analyzing managers’ judgments regarding the introduction of advanced construction tools were classified as Level 1 and pairwise comparison of them was made. The questionnaire on workers aimed at analyzing workers’ evaluation values who use advanced construction tools was classified as Level 2.

**PRODUCTIVITY EVALUATION**

**Introduction of Advanced Tools**

The areas advanced construction tools are practically used encompass diverse areas such as construction, electricity, facility, and safety areas. The advanced construction tools evaluated in this study’s questionnaires are as follows.

In order to collect opinions of managers and workers on the introduction and application of advanced construction tools, an evaluation was made by conducting a survey on the advanced construction tools and their jobs.
Table 2. Advanced Construction Tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Electrical Insulated Tools</td>
<td>Tools for wiring work</td>
</tr>
<tr>
<td>Wheel Dolly</td>
<td>Heavy weight cargo lifting and fixation</td>
</tr>
<tr>
<td>PVC Bender</td>
<td>PVC pipe bending</td>
</tr>
<tr>
<td>Bx/Flex Conduit cutter</td>
<td>Cable cutting</td>
</tr>
<tr>
<td>Cable Striper</td>
<td>High pressure cable cover removal</td>
</tr>
<tr>
<td>Torque Tester &amp; Calibrator</td>
<td>Torque wrench test</td>
</tr>
<tr>
<td>Dump Cart</td>
<td>Carrying construction scraps and wastes out of a site</td>
</tr>
<tr>
<td>Wet / Dry Vacuum</td>
<td>Site cleaning</td>
</tr>
<tr>
<td>Fume Extractor</td>
<td>Removal of fumes during welding</td>
</tr>
<tr>
<td>Torque Wrench</td>
<td>Bolt tightening</td>
</tr>
<tr>
<td>Brady Boy Safety Barricade</td>
<td>For installation on protect areas boundary</td>
</tr>
<tr>
<td>Self-Retracting Fall Limiters</td>
<td>For prevention of falls during work</td>
</tr>
<tr>
<td>Beam Anchor &amp; Beam Trolley</td>
<td>Movable equipment for prevention of falls</td>
</tr>
<tr>
<td>Anchorage connectors</td>
<td>Lifesaving loop installed on a concrete structure</td>
</tr>
<tr>
<td>Flammable Liquid Container</td>
<td>For keeping flammable liquid materials</td>
</tr>
<tr>
<td>Reinforced Barricade Tape</td>
<td>For control of access to and warning against a dangerous area</td>
</tr>
<tr>
<td>Portable Eye Shower</td>
<td>For an emergency measure against foreign materials in the eyes</td>
</tr>
</tbody>
</table>

Modified-AHP Survey Method
The Modified-AHP questionnaire had two parts: one for calculation of weights managers placed importance on at the time when they decided to introduce advanced construction tools and the other for evaluation of workers’ degree of satisfaction relative to existing tools.

Table 3. Scales for Relative Importance

<table>
<thead>
<tr>
<th>Scale</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally important</td>
<td>Two compared elements have equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Slightly important</td>
<td>An element is slightly more important than the other element</td>
</tr>
<tr>
<td>5</td>
<td>Important</td>
<td>An element is more important than the other</td>
</tr>
<tr>
<td>7</td>
<td>Very important</td>
<td>An element is greatly more important than the other element</td>
</tr>
<tr>
<td>2, 4, 6</td>
<td>Middle values of the above scales</td>
<td>Degree of importance is middle between the above scales</td>
</tr>
<tr>
<td>reciprocal</td>
<td>1, 1/2, … 1/7</td>
<td>When the value of an element ( \alpha ) against ( \beta ) is ( n ), one of the above scales, an element ( \beta )'s importance against the element ( \alpha ) is ( 1/n ).</td>
</tr>
</tbody>
</table>

In other words, during the stage of calculating managers’ weights, geometric mean based on pairwise comparison was calculated and during the stage of examining workers’ degree of satisfaction with advanced construction tools, a seven-point scale was applied and arithmetic-geometric mean was calcu-
lated in order to heighten accuracy and reliability of the analysis.

The survey on the introduction and application of advanced construction tools was conducted between September and November, 2011 by visiting construction sites where the tools had been introduced.

A total of 33 questionnaires were collected from 13 managers (39%) and 20 workers (61%). The safety area accounted for the largest number of respondents at 16 (48%) among the areas, followed by the facility area at 5 (15%), the electricity area at 5 (15%), and other areas at 7 (21%). Other areas included construction, paint, and interior design areas.

### Fig. 4. Analysis Result of the Collected Questionnaires’ Respondents

### Table 4: Managers’ Weights for Each Advanced Construction Tool

<table>
<thead>
<tr>
<th>Tools</th>
<th>Convenience</th>
<th>Safety</th>
<th>Workability</th>
<th>Productivity</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Electrical Insulated Tools</td>
<td>0.074</td>
<td>0.537</td>
<td>0.110</td>
<td>0.066</td>
<td>0.213</td>
</tr>
<tr>
<td>PVC Bender</td>
<td>0.053</td>
<td>0.348</td>
<td>0.166</td>
<td>0.137</td>
<td>0.296</td>
</tr>
<tr>
<td>Bx/Flex Conduit Cutter</td>
<td>0.092</td>
<td>0.415</td>
<td>0.094</td>
<td>0.160</td>
<td>0.239</td>
</tr>
<tr>
<td>Cable Stripper</td>
<td>0.099</td>
<td>0.287</td>
<td>0.094</td>
<td>0.074</td>
<td>0.446</td>
</tr>
<tr>
<td>Torque Tester &amp; Calibrator</td>
<td>0.138</td>
<td>0.284</td>
<td>0.094</td>
<td>0.085</td>
<td>0.399</td>
</tr>
<tr>
<td>Wet/Dry Vacuum</td>
<td>0.335</td>
<td>0.157</td>
<td>0.224</td>
<td>0.101</td>
<td>0.183</td>
</tr>
<tr>
<td>Fume Extractor</td>
<td>0.262</td>
<td>0.282</td>
<td>0.146</td>
<td>0.159</td>
<td>0.150</td>
</tr>
<tr>
<td>Torque Wrench</td>
<td>0.084</td>
<td>0.422</td>
<td>0.139</td>
<td>0.088</td>
<td>0.267</td>
</tr>
<tr>
<td>Brady Boy Safety Barricade</td>
<td>0.147</td>
<td>0.420</td>
<td>0.109</td>
<td>0.108</td>
<td>0.216</td>
</tr>
<tr>
<td>Flammable Liquid Container</td>
<td>0.129</td>
<td>0.433</td>
<td>0.152</td>
<td>0.136</td>
<td>0.150</td>
</tr>
<tr>
<td>Reinforced Barricade Tape</td>
<td>0.214</td>
<td>0.214</td>
<td>0.220</td>
<td>0.163</td>
<td>0.189</td>
</tr>
<tr>
<td>Wheel Dolly</td>
<td>0.262</td>
<td>0.292</td>
<td>0.234</td>
<td>0.104</td>
<td>0.109</td>
</tr>
<tr>
<td>Dump Cart</td>
<td>0.215</td>
<td>0.221</td>
<td>0.254</td>
<td>0.258</td>
<td>0.053</td>
</tr>
<tr>
<td>Anchorage connectors</td>
<td>0.138</td>
<td>0.515</td>
<td>0.218</td>
<td>0.045</td>
<td>0.084</td>
</tr>
<tr>
<td>Self-Retracting Fall Limiters</td>
<td>0.218</td>
<td>0.273</td>
<td>0.202</td>
<td>0.180</td>
<td>0.127</td>
</tr>
<tr>
<td>Beam Anchor &amp; Beam Trolly</td>
<td>0.194</td>
<td>0.270</td>
<td>0.189</td>
<td>0.204</td>
<td>0.144</td>
</tr>
<tr>
<td>Portable Eye shower</td>
<td>0.426</td>
<td>0.230</td>
<td>0.145</td>
<td>0.075</td>
<td>0.125</td>
</tr>
</tbody>
</table>
The analysis result of the respondents of the 33 collected questionnaires is as follows.

Workers’ evaluation values of each advanced construction tools derived using a seven-scale questionnaire and arithmetic-geometric mean are as follows.

**ASSESSMENT OF ADVANCED TOOLS**

A comprehensive evaluation of advanced construction tools was made, with a structure of combining managers’ macroscopic insights and managers’ microscopic opinions. Prior to generalization of these two levels, managers’ weights and workers’ evaluation values for advanced construction tools derived earlier were substituted to the equation below to derive the Modified-AHP scores.

\[
Y = \alpha \left( \frac{1 \cdot \beta + 1 \cdot \gamma + 1 \cdot \delta + \varepsilon}{1 + 1 + 1 + 1} \right) + \left( \frac{1 \cdot \beta + 1 \cdot \gamma + 1 \cdot \delta + \varepsilon}{1 + 1 + 1 + 1} \right) + \left( \frac{1 \cdot \beta + 1 \cdot \gamma + 1 \cdot \delta + \varepsilon}{1 + 1 + 1 + 1} \right) + \left( \frac{1 \cdot \beta + 1 \cdot \gamma + 1 \cdot \delta + \varepsilon}{1 + 1 + 1 + 1} \right)
\]

Here, 
\[Y \leq 7.0\]
\[\alpha = \text{Manager’s weight for convenience} \]
\[\beta = \text{Manager’s weight for safety} \]
\[\gamma = \text{Manager’s weight for workability} \]
\[\delta = \text{Manager’s weight for quality} \]
\[\varepsilon = \text{Manager’s weight for productivity} \]
\[x_{m} = \text{Workers’ evaluation value for convenience} \]
\[x_{s} = \text{Workers’ evaluation value for safety} \]
\[x_{w} = \text{Workers’ evaluation value for workability} \]
\[x_{q} = \text{Workers’ evaluation value for quality} \]

The sum of managers’ weights is 1.0 and that of workers’ evaluation values is 7.0, which translates into Y being 7.0. In order to derive sub-elements of workers’ evaluation values for each tool, arithmetic-geometric mean was used.

The Modified-AHP score of each advanced construction tool derived by applying the above equation is as follows. Based on the overall ranks of advanced construction tools, the upper 30%, the middle 40%, and the lower 30% were classified into the upper, middle, and lower classes.

The study was able to look at what elements managers focused on in introducing advanced construction tools and workers did in using them by analyzing the questionnaires filled in by the managers and the workers.

Further, this study presented a relatively successful example by dividing advanced construction tools into the upper, middle, and lower classes based on the Modified-AHP scores of advanced construction tools.

<table>
<thead>
<tr>
<th>Tools</th>
<th>Convenience</th>
<th>Safety</th>
<th>Workability</th>
<th>Productivity</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Electrical Insulated Tools</td>
<td>4.6</td>
<td>6.2</td>
<td>4.8</td>
<td>4.4</td>
<td>5.2</td>
</tr>
<tr>
<td>PVC Bender</td>
<td>2.0</td>
<td>6.0</td>
<td>3.7</td>
<td>4.4</td>
<td>5.0</td>
</tr>
<tr>
<td>Bx/Flex Conduit Cutter</td>
<td>6.0</td>
<td>6.0</td>
<td>5.5</td>
<td>4.1</td>
<td>5.3</td>
</tr>
<tr>
<td>Cable Stripper</td>
<td>6.0</td>
<td>6.0</td>
<td>3.3</td>
<td>4.6</td>
<td>4.1</td>
</tr>
<tr>
<td>Torque Tester &amp; Calibrator</td>
<td>4.3</td>
<td>5.5</td>
<td>3.6</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Wet/Dry Vacuum</td>
<td>4.1</td>
<td>4.3</td>
<td>5.5</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Fume Extractor</td>
<td>4.6</td>
<td>4.1</td>
<td>5.1</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Torque Wrench</td>
<td>5.0</td>
<td>5.0</td>
<td>4.2</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Brady Boy Safety Barricade</td>
<td>4.3</td>
<td>2.8</td>
<td>3.8</td>
<td>2.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Flammable Liquid Container</td>
<td>4.3</td>
<td>5.8</td>
<td>3.5</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Reinforced Barricade Tape</td>
<td>5.9</td>
<td>4.7</td>
<td>5.4</td>
<td>5.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Wheel Dolly</td>
<td>5.3</td>
<td>3.7</td>
<td>4.8</td>
<td>3.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Dump Cart</td>
<td>5.2</td>
<td>6.0</td>
<td>5.6</td>
<td>5.3</td>
<td>4.9</td>
</tr>
<tr>
<td>Anchorage connectors</td>
<td>5.7</td>
<td>6.5</td>
<td>4.7</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Self-Retracting Fall Limiters</td>
<td>4.5</td>
<td>6.0</td>
<td>4.5</td>
<td>4.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Beam Anchor &amp; Beam Trolly</td>
<td>4.0</td>
<td>5.5</td>
<td>4.5</td>
<td>5.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Portable Eye shower</td>
<td>6.0</td>
<td>4.0</td>
<td>4.5</td>
<td>4.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Table 6. Modified-AHP Score of Each Advanced Construction Tool

<table>
<thead>
<tr>
<th>Tools</th>
<th>M-AHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Electrical Insulated Tools</td>
<td>5.60</td>
</tr>
<tr>
<td>PVC Bender</td>
<td>4.89</td>
</tr>
<tr>
<td>Bx/Flex Conduit Cutter</td>
<td>5.48</td>
</tr>
<tr>
<td>Cable Stripper</td>
<td>4.80</td>
</tr>
<tr>
<td>Torque Tester &amp; Calibrator</td>
<td>4.58</td>
</tr>
<tr>
<td>Wet/Dry Vacuum</td>
<td>4.49</td>
</tr>
<tr>
<td>Fume Extractor</td>
<td>4.44</td>
</tr>
<tr>
<td>Torque Wrench</td>
<td>4.62</td>
</tr>
<tr>
<td>Brady Boy Safety Barricade</td>
<td>3.25</td>
</tr>
<tr>
<td>Reinforced Barricade Tape</td>
<td>5.25</td>
</tr>
<tr>
<td>Wheel Dolly</td>
<td>4.35</td>
</tr>
<tr>
<td>Dump Cart</td>
<td>5.49</td>
</tr>
<tr>
<td>Anchorage connectors</td>
<td>5.63</td>
</tr>
<tr>
<td>Self-Retracting Fall Limiters</td>
<td>4.88</td>
</tr>
<tr>
<td>Beam Anchor &amp; Beam Trolley</td>
<td>5.02</td>
</tr>
<tr>
<td>Portable Eye shower</td>
<td>4.97</td>
</tr>
</tbody>
</table>

Their ranks were derived based on the Modified-AHP score of each of advanced construction tools.

Table 7. Each Advanced Construction Tool’s Rank

<table>
<thead>
<tr>
<th>Tools</th>
<th>Rank</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage connectors</td>
<td>1</td>
<td>Upper</td>
</tr>
<tr>
<td>Rated Electrical Insulated Tools</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Dump Cart</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Bx/Flex Conduit Cutter</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Reinforced Barricade Tape</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Beam Anchor &amp; Beam Trolley</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Portable Eye shower</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>PVC Bender</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Self-Retracting Fall Limiters</td>
<td>9</td>
<td>Middle</td>
</tr>
<tr>
<td>Cable Stripper</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Torque Wrench</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Torque Tester &amp; Calibrator</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Wet/Dry Vacuum</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Flammable Liquid Container</td>
<td>14</td>
<td>Lower</td>
</tr>
<tr>
<td>Fume Extractor</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Wheel Dolly</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Brady Boy Safety Barricade</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSIONS
This study applied the Modified-AHP by focusing on how to enhance labor productivity for productivity improvement as a whole and collected opinions on each advanced construction tool from managers and workers. This study was able to figure out major elements managers and workers considered in each advanced construction tool. However, the number of survey samples was so small, which resulted in relatively low reliability. Therefore, future study should derive weight by categories like electricity, facilities, and safety in order to come up with measures for the introduction of each of advanced construction tools. Moreover, reliability should be heightened by increasing the number of survey samples on advanced construction tools.

ACKNOWLEDGMENT
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REFERENCES
An object library approach for managing construction safety components based on BIM.

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Purpose One of the potential solutions for designers’ lack of safety expertise in design decision is utilizing IPD to allow for constructor input. But how this is to be done is often unclear because few cases from either practice or research can be found. In this study we tried to develop an IPD-method to facilitate ‘safety in design’ with the contractor’s knowledge using an object-oriented programming (OOP) approach for design decision based on BIM. Method Our principal research method is simulation of the decision process in OOP2 in a case study. The integration of contractor’s knowledge in construction safety is achieved by setting parameters for construction safety investment with contractor’s input into a construction safety component library (CSCL) e.g. scaffolds, boards, barriers, etc. under the proposed IPD-framework. Results & Discussion A prototype of CSCL using one OOP-language, C#, is developed in Microsoft Visual Studio 2010 to Autodesk Revit 2012 with a completed construction project for demonstration. The results show that CSCL is a semi-automated tool with contractor’s knowledge of construction safety for design decision. It is consistent with the theory that BIM is not only a type of software but a knowledge repository for in-depth collaboration, information sharing and knowledge re-use among all parties involved in a project. New issues and rethinkes including level of detail (LoD) on company’s library, IPDevaluation metrics, and BIM-development method addressing construction safety management, are also recommended in the final part.

Keywords: information technology, design decision, CSCL, BIM, IPD

INTRODUCTION

Safety is a major issue across global construction industries; loss of life through construction accidents is unacceptable. While the physical task of putting together buildings and infrastructure remains a locally embedded physical activity, it is also changed by the digital economy, which brings with it new “splintered yet connected” ways of working across global networks of design services and product supply 18. It is suggested more extensive co-operation between contractor and designer is needed to improve the safety planning methods and effectiveness11.

“Safety in Design” has been stated and highlighted by many researchers18, but recent research shows that ‘many designers still think that safety is ‘nothing to do with me’ although there are a small cohort who want to engage and are having difficulty doing this because they do not fully understand what good practice looks like5.” This is due to the fragmentation and document-centric nature of the traditional AEC industry2. Designers usually don’t have knowledge of site safety arrangements in practice as contractors. To address these issues, Building Information Model (BIM) appears and brings about both technology and process innovation to traditional AEC industry. In this regard, the integration of construction safety information for design decision with the contractor’s knowledge based on BIM is to be studied in this research. The general objectives of the research are to improve the safety performance of the construction of facilities, specifically through improving the link between design and the construction process within a proposed IPD framework.

LITERATURE REVIEW

“Safety in Design” Zhou et al., 2011 gave a comprehensive review on “Construction Safety in Design” both in academic research studies and practices. Evidence indicates that “the quality and nature of design do have some impacts on construction safety18” However, constraints come from the traditional design-bid-build contracting arrangements, complex hierarchy of subcontracting, organizational distance, designers’ liability concerns and immaturity of new forms of procurement etc. 18. “Design for construction safety requires collaboration of the designer, owner, constructor, and other project parties for it to be meaningful18”, and “there is more work to do to establish a robust evidence base to show the aspects of construction safety where design has the largest role to play18”. Hence, the first Research Question is raised: How can we integrate the contractor’s knowledge of construction safety into design?
Construction Safety and BIM
Ku and Mills, 2010 reviewed and summarized the current Design-for-Safety Tools, and classified them in four types: Hazard recognition (Checklists, Computer software (ToolBox)), Risk assessment (Risk mitigation forms Computer software (ToolSHeD)), Procedure (Review tools (CHAIR)), and Visualization (3D/4D CAD Virtual construction)\textsuperscript{12}. It was then suggested that “BIM offers opportunities to assist design teams to automate hazard recognition and design optimization processes”\textsuperscript{12}. Developments in BIM and Computer Tools for Safety were then categorized into two areas of computational support: design review and simulation. Research Suggestions for future BIM Tools for Safety were concluded as 1) 4D model integration with hazards database; 2) Development of custom rules for safety considerations; 3) Level of Details (LoD) for construction equipment and workers; and 4) Integrated agent-based modeling for design changes, delays etc.\textsuperscript{12}. But these were all function/technology driven approach/strategy, and lack of consideration on collaboration of multi-parties in a project.

BIM and Object Library
BIM platforms have various libraries of predefined objects that can be imported for use. These are helpful by eliminating the need to define them yourself. And in general, the more predefined objects, the more helpful\textsuperscript{6}. “Currently, there is little effort to standardize the structure of object information beyond geometry\textsuperscript{6}.” Furthermore, if the BIM tool is customized for architectural practice, even more efficiency gains can be achieved towards a better design practice\textsuperscript{6}. And “One crucial precondition regarding BIM-based site planning in real-life projects would be that planner has a predefined set of 3D objects over most often used site equipment. This would facilitate and accelerate site planning clearly\textsuperscript{6}.” But what kind of safety components are to be composed in the library and how to integrate the Construction Safety Component Library for design decision? These also serve as the second Research Question.

IPD
Implementing BIM effectively does not only require learning new software applications, but also how to reinvent the workflow, how to train staff and assign responsibilities, and changing the way of modeling the construction\textsuperscript{5}. At the mention of BIM, the topic on Integrated Project Delivery (IPD), which is a comprehensive procurement method, is followed among researchers and practitioners. BIM is not only a type of software but a human activity that ultimately involves broad process changes in AEC industry\textsuperscript{5}. Generally, “IPD is a deeply collaborative process that uses best available technology, but goes beyond merely the application of digital tools, such as Building Information Modeling\textsuperscript{5}.” IPD seeks to “improve project outcomes through a collaborative approach of aligning the incentives and goals of the project team through shared risk and reward, early involvement of all parties, and a multiparty agreement\textsuperscript{15}.” And one of the potential solutions for designers’ lack of safety expertise is utilizing IPD to allow for constructor input\textsuperscript{17}. But “how” remains confusing to us because only a few cases in both practices and research studies can be found. More specific research studies should be carried out in this area to enrich the theory of IPD and more implementation should be conducted among industries for best practices.

RESEARCH METHODOLOGY
Construction Safety Component Library (CSCL)
The Construction Safety Component Library (CSCL) in this paper is defined as an Object Library consisting of construction safety site equipment including General Equipment e.g. Metal Fencing, Protective Net, Catch Fan etc. and Personal Protective Equipment e.g. Helmet, Reflective Vest, Safety Boot etc. with generated performance indicator for design decision. The Object here refers to the Construction Safety Component or equipment.

Construction Safety Investment
The specific construction safety information or performance indicator is a prerequisite for the model established in this study. Requirements and criteria should be met as: 1) As a variable dependent on both design decision and the contractor’s input; 2) easy to be captured to represent the contractor’s knowledge, technique, experiences etc. and reflect the contractor’s competence in safety performance; 3) easy to be generated through the model and the result is obvious enough to evaluate the design decision. Slaughter, 2003 proposed a Dynamic Process Simulation Model of Construction Activities, which could generate the impact of design alternatives on construction cost/schedule/safety. The safety in the model was defined as the index of the exposure of workers to dangerous conditions calculated from the task duration matched to the OHSA-identified causes of worker injury\textsuperscript{15}. But recent research showed that the occupational accidents suffered by construction workers at different hours of the day are different\textsuperscript{14}, thus the task duration may not reflect the situation in this regard. The safety performance generated by model was based on the consequence and loss by injuries but not the prevention measures like investment on safety equipment and training etc. which should form the strategy of “Prevention through Design”. Gambatese et al., 2005 pointed “designing for safety has resulted in positive impacts to construction cost\textsuperscript{18}, and furthermore, if the entire life cycle of a project and sustained purchasing of construction...
services are considered, the potential benefits are expanded as design changes which initially may be costly become long-term benefits as a result of lower construction costs and improved safety during operation and maintenance. Compared with the requirements/criteria above, the Construction Safety Investment among Construction Schedule Delay and Construction Plan Change etc. is to be regarded as the indicator and the specified construction safety information for integration.

Sun, 2010 reviewed and classified the Components of Safety Investment into two main categories: physical and cultural. While physical inputs include another two main categories: on-site safety management and designing for safety. On the other hand, cultural input refers to the cultivation of safety culture in both project and organizational level. The simplified Construction Safety Investment model for design decision in this study is:

\[ CSI_i = (\sum GE_{ij} + \sum PPE_{ij}) \cdot (1 + \alpha_k) \]

Where,

- \( CSI_i \) - Construction Safety Investment based on Design Decision \( i \).
- \( GE_{ij} \) - Cost of General Equipment \( j \) based on Design Decision \( i \).
- \( PPE_{ij} \) - Cost of Personal Protective Equipment \( j \) based on Design Decision \( i \).
- \( \alpha_k \) - Safety Cultural Adjustment Coefficient of Contractor \( k \), which also needs to be refined by researchers and practitioners.

Development of the Prototype

The prototype is developed in C# in Microsoft Visual Studio 2010 IDE based on Microsoft .NET Framework. Thus C#.NET is used to develop a prototype of the Object Library for CSCL. ADO.NET (ActiveX Data Objects for .NET) is used to access the program to the Microsoft SQL Server database, which stores the contractor's input of the quantity and price information in the CSCL. The link to the database allows for the track of the modification of CSCL for record and documentation, and retrieval of contractor's knowledge. ADO.NET provides an easy, efficient way to access database. It is a set of computer software components that programmers can use to access data and data services. And it is a part of the base class libraries that is included within Microsoft .NET Framework. ADO.NET is commonly used by programmers to access and modify data stored in database systems with many pre-defined dataset objects. The system diagram of the prototype is shown in Fig.1.

RESULTS

To test the applicability of the model, which refers to the involvement of the contractor for design decision and knowledge retrieval in the process, a real construction project with the contractor was selected for demonstration. The façade of a building involves more design work by the contractor compared to other parts, and the contractor would have more experience and knowledge in design and construction/fabrication of the façade. The selection criteria for the project were then set to a building with typical and complete façade with the contractor's Safety Standards/Instructions/Requirements for the project's façade engineering. The model is configured to use the detailed design attributes for a specific project as input of the design alternative.

A completed Construction Project A, including shop drawings, construction method, plan and schedule with Contractor A in Hong Kong was selected according to the criteria. Although it is a completed one, it does not affect testing the applicability of the model. Project A is an office building of 69F to the main roof, with a footprint of 51.6 by 51.6m, with the floor-to-floor height of 4m, all enveloped with glass curtain walls in the exterior enclosure system. The building components: glass curtain walls (only one facet out of four for simplification) with its attributes represents the design decision, and the design alternative would be the length, height, and density etc. of the glass curtain wall panels in this facet; the Construction Safety Components are selected according to the Chapter of Working at Height and Chapter of Personal Protective Equipment in the Book of Safety Standards and HS&E Concerns for Project A provided by Contractor A, namely Metal Fencing, Protec-
tive Net, Catch Fan and Gondola as the general equipment, and Helmet, Reflective Vest, Safety Boot etc. as the Personal Protective Equipment, which represent the contractor’s knowledge on Construction Safety Investment with the input value to their attributes. The whole project was then established in Autodesk Revit Architecture 2012 as a BIM platform with good quality in visual presentation and information inquiry in 3D view. The required quantity and price of each Construction Safety Component for the original Design Decision were then got from Contractor A according to the project’s construction method, plan and schedule, shown in the following tables.

Table 1. Attributes of Construction Safety Components (General Equipment) with quantity and price information

<table>
<thead>
<tr>
<th>type</th>
<th>Gondola (Length×Width×Height)</th>
<th>5.0m×0.5m×0.9m</th>
<th>31.4m×3.0m×N/A</th>
<th>33.6m×3.0m×N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantity</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>price</td>
<td>HK$200000</td>
<td>HK$23500</td>
<td>HK$25200</td>
<td></td>
</tr>
<tr>
<td>safe working load and max. no. of persons</td>
<td>G/F to Roof</td>
<td>69/F to Roof</td>
<td>G/F to 69/F</td>
<td></td>
</tr>
<tr>
<td>safety harness with independent lifeline and fall arrester</td>
<td>200kg/each &amp; 2/each</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>price of safety harness</td>
<td>HK$50**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>remarks</td>
<td>*(provided by the subcontractor, operation cost around $2,000/day)×100 days</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Attributes of Construction Safety Components (Personal Protective Equipment) with quantity and price information

<table>
<thead>
<tr>
<th>Personal Protective Equipment</th>
<th>quantity</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>helmet</td>
<td>6</td>
<td>$20/unit</td>
</tr>
<tr>
<td>reflective vest</td>
<td>6</td>
<td>$20/unit</td>
</tr>
<tr>
<td>safety boot</td>
<td>6</td>
<td>$250/unit</td>
</tr>
<tr>
<td>safety harness</td>
<td>6</td>
<td>$50/unit</td>
</tr>
<tr>
<td>cotton glove</td>
<td>N/A</td>
<td>$5/unit</td>
</tr>
<tr>
<td>leather glove</td>
<td>6</td>
<td>$30/unit</td>
</tr>
<tr>
<td>ear defender/plug</td>
<td>N/A</td>
<td>$2/unit</td>
</tr>
<tr>
<td>safety spectacles (general purpose)</td>
<td>N/A</td>
<td>$90/unit</td>
</tr>
<tr>
<td>safety goggle (dealing with chemicals)</td>
<td>N/A</td>
<td>$120/unit</td>
</tr>
<tr>
<td>dust mask</td>
<td>N/A</td>
<td>$2/unit</td>
</tr>
<tr>
<td>cartridge respirator</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The design decision would be an iterative process with the early involvement of the contractor in this model, the generated Construction Safety Investment would be the determinant for the design decision, and if the result doesn’t meet the criteria of the Investment, the building components (the glass curtain walls in the one facet) would be redesigned and the process would be run again. The model also enables the track of the modification of Construction Safety Components in the database for record and documentation. The value of $\alpha_5$ is assumed to be 0.32 to run the program. The generated results (HK$1,719,427) within the iterative process and track of modification in the database are illustrated in the figures below.
The prerequisite to implement the model in this study is the Input based on the contractor's knowledge (e.g. Safety Cultural Adjustment Coefficient $\alpha_i$ proposed in the model). More researches should be carried out with leading contractors to establish their Safety Libraries for knowledge management in their safety performance. And more evaluations of the model should be conducted in terms of different building types (commercial, residential, public, industrial etc.) and ongoing projects, the decision on design alternatives should be classified in different phases: conceptual design or detailed design etc., the impacts should be collected on safety decisions, on-site safety performance and barriers to its implementation.

CONCLUSIONS

“One of the most fundamental advantages that IPD affords is the ability for all parties to be present and involved with a project from the earliest design phase. Early collaboration, under the right conditions, can directly address the problem of fragmentation between design and construction professionals that results in inefficient work practices and costly changes late in the construction phase.” And one of the potential solutions for designers’ lack of safety expertise is utilizing IPD to allow for constructor input. But “how” remains confusing to us because only a few cases in both practices and research studies can be found. The model established through Input from the contractor using Object Library in this research is an example for illustration. And it is a method for the early involvement of contractors with their knowledge for design decision from the perspective of construction safety. The general objectives of the research are to improve the safety performance of the construction of facilities, specifically through improving the link between design and the construction process within a proposed IPD framework.

The potential link of design and construction is use of the model by designers and contractors to analyze design alternatives to improve their planning and control capabilities in safety performance. The company could use the model with customized safety components for a specific project to understand the nature of their activities and the impact that design alternatives would have on their investments in construction safety. These analyses could provide a critical feedback system for design and construction organizations to learn across projects to improve their internal competencies in safety performance. It could also provide a means to assess and improve the designs, components, systems, and process of construction projects, as well as to improve the efficiency of the design and construction processes.
The functionality and quality of the Library in BIM platforms were described as “Library objects will need to be accessed and integrated into projects using the standard nomenclature defined within that BIM platform for proper interpretation. Full integration includes object classification, naming conventions, attribute structure etc.” And a well-designed library management system should include “the ability to create catalogs of objects in a library (Library views) for specific projects or building types, and functionality for resolving discrepancies between object names and property sets across catalogs of objects.” The future research directions could be identified as Level of Details (LoD), Meta-data, Ontology and Taxonomy of CSCL for generalization, and the IFC-compliant description for interoperability and integration.

References
Positioning of human resources in a construction environment using Zigbee

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Purpose The purpose of this work is to explore the feasibility and accuracy with which people can be located in a construction site using Zigbee technology. Such positioning systems will enable the tracking of workers and this is critical in work areas such as tunnels and other constrained spaces which can be hazardous. Furthermore, such systems can detect worker congestion and work in unallocated areas which can lead to better planning and improved productivity. Earlier work on positioning has explored technologies such as GPS, RFID, WLAN, Bluetooth. The cost associated with most of these methods has been significant and limits widespread use within a construction site. Hence configuring a cost-effective technology was also a key requirement of this study. Method The investigation was done in three phases. In the first phase the Zigbee system was configured in a laboratory environment and accuracy of positioning was established. In the next phase, the system was mounted on a construction helmet and tests were conducted within enclosed spaces of a construction site. In the final phase the system mounted on a helmet was worn by a worker and tested outdoors on a construction site. In all phases the factors affecting the position accuracy were analyzed. Results & Discussion The seven positions identified in the table of the final phase of investigation correspond to the division of the site into grids. The total number of positions evaluated and the number of these positions which were correctly classified are specified in the table. It can be seen that the accuracy of the classification ranged from 74.3% to 93.3%. It was found that the accuracy varied based on the distance of the position from transmitters as well as proximity of the position to the edge of adjacent grids. Based on these investigation guidelines on the configuration and usage of Zigbee based networks for positioning construction personnel were developed. In addition to the technological feasibility a cost comparison was also done and it was found that the Zigbee technology could be implemented at about 1/10th of the cost of WLAN and other technologies. Although this technology was only tested on construction workers it is directly applicable for location of other subjects such as differently abled or elderly persons whose location needs to be monitored remotely.

Keywords: automation, positioning, Zigbee

INTRODUCTION

Construction is one of the largest and fast developing industries in Indian subcontinent. When the level of automation of construction in India is compared with developed countries, it is apparently much less and needs significant improvement to ensure pace of development is maintained. Application of software like Primavera and Microsoft project have already been in place and play an important role in planning and scheduling of most construction projects. Automated data collection & sensing technologies like RFID (Radio Frequency Identification), WLAN (Wireless Local Area Network), GPS (Global Positioning System), WSN (Wireless Sensor Network) etc. have gained importance in recent times, however applications are very limited. Positioning of resources in indoor environment always draws attention as it can significantly help in safety and risk management, asset management and maintenance, productivity and time management. Research on wireless positioning systems have employed Ascension technology1, Differential GPS (DGPS), Wireless assisted GPS, Ultra Wide Band (UWB), Proprietary microwave solutions, Wireless LAN (WLAN)2, Bluetooth, Infrared, Radio Frequency Identification (RFID), Ultrasonic, GSM and CDMA mobile technologies. Wireless technologies gained importance in customer friendly application and helped in resolving various problems in the field of medical, industrial, public safety, logistics and transport systems. The process of finding location information using wireless technologies is called location sensing, geo-location or radiolocation. This study introduces an indoor object tracking method using Zigbee module under IEEE 802.15.43 which gives meter level accuracy. Automatic location can be applied in many real world applications. Location detection of warehouse products, tracking of hospital personnel as well as patients, firemen detection in a building on fire, detection of police dogs trained to find explosives in a building, tracking maintenance tools and equipment’s and tracking of pipe spools and other spares in a large manufacturing plant. Management of materials, machinery and vehicles can be controlled by computers and drivers whereas control of labor is much more difficult and hence requires more attention.
Indian construction industry is labor driven and management of labor forms an integral part of major projects. Tracking of labor in indoor environment has always posed problems as there is no proper automated technique in construction environment particularly in the Indian context. The labor working inside tunnels, congested areas and similar environments have to be tracked so that there should be clear idea about the number of labors employed inside these environments in case of an emergency. The conventional system of written entry of in and out time in register has many limitations.

Another important issue is productivity of labor employed in indoor environment. From field visits, it was observed that most of the labors employed inside the tunnel or indoor environment are idle for significant amount of time and there was no effective monitoring. The same has been observed in congested indoor environments of nuclear power plants and it was impossible to know how many labors are working in a particular area. Hence an automated system to monitor the movement of labor is essential.

Through such a system, positioning and tracking of labor, the number of workers, proximity to hazards and state of labor i.e. whether a labor is static or dynamic can be determined and appropriate action can be taken based on the situation.

As such systems have the potential for widespread use it has to be economical to implement and give reasonably good results. The objective of this study was to explore various technologies which can be used to implement such a positioning system and develop a cost-effective prototype implementation for an appropriate technology.

The next section of this paper reviews factors influencing positioning and various positioning technology. This is followed by system architecture of a Zigbee based technology. The calibration, implementation and testing details of the technology are presented next and finally the conclusions of the study are discussed.

**Classification of Positioning Systems**

Liu et al. (2007) and Zhang et al. (2010) classified the various positioning systems used in the industry. Positioning of one’s own location has always gained importance since early times. A study on the constellation of celestial bodies was also a tool for knowing one’s own location. Achievements in mathematics and hence the laws of trigonometry, along with inventions of novel measuring instruments lead to the development of many positioning techniques. Principle of localization follows the same principle as in the ancient times. The constellation of stars used to deduce the location is now replaced by reference points with respect to which the location is tracked. Similarly positioning can be also classified into client based, network based and network assisted (Alex Varshavsky (2009)).

Client based positioning does not depend on the network infrastructure to track themselves, whereas the second one employs the network infrastructure to calculate the location of the object. The network assisted incorporates the facilities of both to get the location of the mobile user.

The selection of a positioning technique depends on various factors. Even though there are many indoor positioning techniques, there is no single technique which can satisfy the entire criterion. A positioning method which is apt for one use may not be suitable for another purpose and hence should be selected wisely.

**Parameters influencing selection of techniques**

The significant parameters which decide the selection of a particular technique are listed below:

- **Accuracy**
  One of the most important criteria for selection of a technique is accuracy. Accuracy can vary from millimeter range to kilometer range depending on the technology used. As the accuracy increases, performance of the system is considered to be better. Accuracy can be used as a main parameter for biasing the selection of a positioning technique.

- **Precision**
  Precision is the measure of robustness of a positioning system. The ability of a positioning system to reproduce the same results over multiple trials reveals the precision of a tracking system. Accuracy gives the error whereas the precision gives the consistency of a system.

- **Complexity and Responsiveness**
  The complexity of location system refers to complexity of the hardware, software and operation factors involved in implementing a particular system. The complexity of a system is indicated by location rate. The delay between target moving to a new location and system reporting the new target location gives the lag which in turns gives the location rate.

- **Robustness**
  The ability of a positioning system to work even in the harsh and unexpected condition is referred to as the robustness of the system. For example suppose a system is not receiving signals from all the sources and if the system is able to give the location of target by processing existing or available signals, and then the system is referred to as robust.
Scalability
The extent of coverage of a positioning system in terms of both area and density is known as the scalability of a tracking system. The system should ensure proper working even if the scope gets widened to a reasonable limit. Another measure of scalability is the dimensional factor of the system, whether an object can be located in 2 D or 3 D.

Cost
Cost of a system involves many factors which include money, time, space, weight and energy. Time of installation and maintenance is the time factor. The system may have tight space and weight constraints. Usage of passive energy or active energy sources have a significant effect on the system and hence the energy factor.

Power Consumption
The usage of power should also be considered especially when battery driven mobile units are involved.

Compatibility
The selected technology should be compatible with the working labors and also with the human beings who live within the range of the positioning system.

Khoury & Kamat (2009) studied the use of WLAN (Wireless Local Area Network) technique for user localization in indoor construction environment. Wireless positioning systems can be classified based on different measurement techniques adopted to position the location of Mobile Station (MS). The common measurement techniques used today are Trilateration, Triangulation, Proximity, hyperbolic lateration, Fingerprinting and Dead reckoning techniques. The trilateration method computes the location by measuring the distance between fixed reference nodes of known location and the MS. The technique adopts the principle of Time Of Arrival (TOA) and signal strength attenuation for the calculation of distance.

The method of triangulation uses the principle of AOA (Angle of Arrival) for the positioning of MS. The angle of arrival of radio signals is obtained to derive the location of MS. Directional antennas are used for obtaining AOA. The point of intersection of two angular rays are sufficient for locating the position of MS in 2-D; but in practice, more than two reference nodes are considered in order to reduce the errors in angular measurement. When trilateration uses the TOA (Time of Arrival) for location determination, hyperbolic lateration uses the TDOA (Time Difference of Arrival) for estimating the position of MS. The difference between signal arrival times at two reference points gives the location of MS on a hyperbolic line where the reference nodes form the foci. Few examples of system that uses TOF (Time of Flight), AOA and TDOA are Cricket, Active bat, Ubisense, Sapphire darts etc. Fingerprinting or location pattern matching technique uses the measurement of RSS and its unique behaviour in a particular location forms the basis of the method. In this method the location of the MS is calculated by finding the closest match from the fingerprint database of the area. The disadvantage of using this method is the factor of time as it consumes lots of time for creating the RSS database. The advantage of the system is the fact that MS does not have to search for the signals from all the three reference nodes for location tracing as this technique depends only on the pattern matching. Proximity is another method for localization in which closeness of an MS to a particular reference node is used to find the location of the user. It can be direct contact or even the presence detected by sensors at reference nodes. This method may not reveal the identity of the MS, for that additional arrangement should be incorporated. Some of the examples include active floor which uses step up sensors for location identification by direct contact, active badge using infrared, airbus which works on the principle of differential air pressure, camera, Bluetooth, RFID and cell of origin method using cell phones.

Dead reckoning is the method of positioning by calculating from the known previous location of the MS, and its direction of travel, speed and elapsed time. This method is basically on the assumption that the direction and the average speed of travel of MS from the last known location is either known or can be estimated. The commonly used sensors for dead reckoning technique are accelerometers for measuring the acceleration, odometers for measuring the distance travelled, and gyroscopes for assessing the direction of travel.

The positioning systems are again classified on the basis of different methods or systems adopted for localizing. The wireless methods commonly used for location tracking are Radio frequency (RADAR, SPOT ON), Infrared, Bluetooth, Ultrasound, Inertial navigation systems and sensors. The signal characteristics like propagation delay, reflection, scattering and diffraction affect all the above mentioned technologies. The other factors like range, available bandwidth, regulatory constraints, interference, power constraints, safety and cost of the technology can also influence the selection of the suitable technology.

Wireless Sensor Networks (WSN)
WSN uses accurate and low cost sensors for localization of MS. The sensors work on IEEE 802.15.4
infrastructure and operate at a frequency of 2.4 GHz. The two major sensor network standards are IEEE 802.15.4 PHY (PHYsical Layer) and MAC (Medium Access Control) layer for LR WPAN (Low Rate Wireless Personal Assisted Network) and Zigbee networking17 and application standards. The Zigbee protocols use RSS for the localization purpose. The thesis work is based on localization system based on Zigbee protocol using RSS. Fingerprinting technique is adopted and Euclidean Distance algorithm is considered for tracking the MS.

Bob Heile, The chairman of Zigbee Alliance defines ZigBee as “a rapidly growing, worldwide, non-profit industry consortium” whose mission is “to define a reliable, cost-effective, low-power, wirelessly networked, monitoring and control product based on an open global standard.”18 It also has the following features.

- Low power consumption compared to Wi-Fi and Bluetooth
- Doesn’t require any extra infrastructure
- Cost effective
- Works without internet access
- Mesh Self-Healing network
- Good range (10m to 100 m)

Various technologies were considered for the study and finally Zigbee protocol was selected for localization. The comparison between different technologies considered during the initial study is given in Table 1.

Table 1. Cost comparison between different tracking technologies

<table>
<thead>
<tr>
<th>Technology/ Model</th>
<th>Vendor</th>
<th>Infrastructure</th>
<th>Range</th>
<th>Cost</th>
<th>Total cost unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID</td>
<td>Gooroo</td>
<td>RF reader</td>
<td>50-100m</td>
<td>$1000</td>
<td>$1000</td>
</tr>
<tr>
<td>Barcode India</td>
<td>RF reader</td>
<td>RFID tag</td>
<td>7m</td>
<td>$500</td>
<td>$5000</td>
</tr>
<tr>
<td>Arimosoft</td>
<td>RF reader</td>
<td>RFID tag</td>
<td>10-110m</td>
<td>$500</td>
<td>$5000</td>
</tr>
<tr>
<td>MIF</td>
<td>Mobile CCI</td>
<td>UHF RFID reader</td>
<td>10-165m</td>
<td>$1000</td>
<td>$10000</td>
</tr>
<tr>
<td>Mini MIF</td>
<td>Mobile CCI</td>
<td>UHF RFID reader</td>
<td>10-165m</td>
<td>$1000</td>
<td>$10000</td>
</tr>
<tr>
<td>Zigbee</td>
<td>Maxstream xbee</td>
<td>Long range</td>
<td>15-30m</td>
<td>$500</td>
<td>$5000</td>
</tr>
</tbody>
</table>

In this study, the feasibility of using Zigbee 802.15.4 protocol is evaluated for positioning of human resources and the effectiveness of Zigbee based tracking system is studied in actual construction site, both in indoor and outdoor environments. The work focused mainly on the use of Zigbee Maxstream Xbee2 module of IEEE 802.15.4 standard for location estimation. The study also focused on the use of Audirno UNO3 MCU platform and its implementation for the object tracking application. The research used fingerprinting technique for location estimation. The primary step of the research was to select appropriate technology and algorithm for location estimation through literature review of various positioning technologies. Zigbee protocol (802.15.4) was selected for the study and Maxstream Xbee module was selected as the module for location estimation system. The next step in the research was to study about Xbee module and Arduino UNO board through appropriate literature review. The selected modules were then configured for tapping RSSI (Received Signal Strength Intensity) using various command modes. Fingerprint models were then created and location identification system was developed on the basis of developed models. The location estimation system was then experimented for its performance parameters through various tests conducted at actual construction sites.

LOCATION ESTIMATION USING ZIGBEE

RSSI Mapping

The Indoor localization of human resources using Zigbee is based on location fingerprinting technique. Kaemarungsri (2005) has studied the use of location fingerprint technique. A fingerprint based on RF is created to represent a particular location. RSSI of various RF waves are used for creating a location fingerprint. The basic assumption behind the creation of a location fingerprint is uniqueness of RF signature at a particular location inside the building. The RSS pattern at a particular location inside the building is assumed to be unique and hence an authentication is created. The fingerprint is usually designated along with the location information. The fingerprints along with their location information are maintained in a database and the same is referred during the tracking or online phase to estimate the location. The location information about an indoor location can be stored in two forms; either in the form of coordinates or as a location indicator. The indicator in coordinate system may have one dimension to five dimensions where the five dimensions include three dimension space and two orientations. A location information in two dimension with orientation can be expressed as \( L = \{(x, y, d)| x, y \in \mathbb{R}^2, d \in \{\text{North, East, South, West}\}\) 19.

RSS is found to fluctuate lots with time for each access point and location. The behaviour of RSS is highly variable, hence needs to be studied for better results. The behaviour of RSS can be observed by recording its static behaviour, approximating its distribution or by maintaining the whole dataset. The pattern of RSS and its analysis is required for the selection of suitable location estimating algorithm. The location fingerprint is stored as RSSI values in
the form of arrays and the size of the array depends on the number of access points that can be heard. Static analysis of RSS data is called pre-processing and is considered important. The pre-processing refers to the cleaning of raw data. Cleaning may consist of encoding, noise reduction, feature extraction/selection etc.

To create a basis fingerprint, a set of RSSI values is collected for a period of time from all the access points at a particular location. This basis is called a prototype. Then, the average RSS of each access point is calculated and recorded as an element in the location fingerprint. For an area that can receive signals from N access points, the location fingerprint can be expressed as a vector of average RSS elements \( \beta_i \):

\[
F = (\beta_1, \beta_2, \ldots, \beta_N)^T
\]

This location fingerprinting technique uses the authentication of measured RSSI to estimate the location of the mobile station. By knowing RSSI at known locations and the instantaneous RSSI, the position is estimated. The RSSI at known locations should be collected and stored at the central database as Radio map or Radio signatures. This type of positioning systems does not require any extra infrastructure as it depends only on the capability to display the RSSI. Hence it is simple to deploy this technique compared to other techniques. Indoor positioning methods also encounter the problem of NLOS (Non Line Of Sight) and hence the method of AOA (Angle of Arrival) and TDOA (Time Difference of Arrival) becomes less applicable in indoor environments.

**Finger printing Technique**

The Finger printing was implemented in two phases: The training phase and the tracking phase. In the training phase, a 2-D virtual map is created and the area of interest was divided into grids. The entire area of scope should be covered and reference points should be evenly distributed. Mobile user with active tag is made to stand in all the reference points and corresponding RSSI from the tag is noted from the access point. With all the RSS obtained, a database of RSS is created which is called the Radio Map. Objective of the training phase is to create a signal information database. It acts as a base or underlying reference for the tracking phase. The RSS obtained might have lots of interference with noise signals and all those disturbances should be cleared or leveled. The dataflow in training phase is shown in Figure 1.

In the second phase, a MS (Mobile Station) will report a sample RSSI from different access points and the same is send to the base station. The location of MS is estimated at the base station using proper algorithm. The most commonly used algorithm for location estimation is Euclidean distance algorithm. It computes Euclidean distance between reported RSSI and RSSI’s at each point in the Radiomap and returns that location with the smallest Euclidean distance. A good database should be created with proper planning and system design. If location information is not accurate, creation of more fingerprint locations are preferred. Factors such as number of access points and grid spacing should be decided on the basis of system performance. Parameters that improve the accuracy and precision to a greater extent are still not clear. The dataflow in training phase is shown in Figure 2.

**Location estimation**

To estimate the location, an algorithm is created called as location estimation algorithm or positioning algorithm which exploits the relation between location information and location fingerprint in order to determine the location from sample of RSS signals. Euclidean Distance algorithm is a method of location estimation in which a set of constant fingerprints which includes mean RSS vectors are used. The set of mean RSS vectors are collected during the offline phase and stored to represent a particular location. The RSS vectors obtained during the online phase is
then mapped to previously stored fingerprint vector and mapping is then converted into position of the user. The Euclidean distance algorithm calculates the distance between the online phase RSSI vectors and the offline RSSI vectors and the returns the position having the smallest distance or least error as the location of the user.

Location estimation using Zigbee protocol was carried out using Maxstream Xbee module, Arduino UNO microcontroller boards and switching boards to act as a platform for connecting Xbee and Arduino. The Xbee module was configured in API mode and API operation requires that communication with the module be done through a structured interface. The API command mode in the Xbee module has a definite framed structure for transmitting and receiving the RF packets. The serial data transfer is included in the frame work of API mode and hence there is no need of switching between data mode and command mode. The major limitation of switching time in AT command mode is hence removed in the API command mode. The configuration and burning of data into Xbee modules were done using X-CTU software which is open source software for Xbee. The Xbee is connected to the system in which X-CTU is installed and the program is executed. The first step before writing data is to check and establish the connection with the modem. The connection is tested in the PC setting tab of the X-CTU window. The API command mode can be directly burned into the Xbee module using X-CTU interface. The modem configuration tab of X-CTU was used to set the API mode. The power level for transmission of RF packet can also be set in the X-CTU window.

Arduino Uno MCU was configured to send and receive the packets of RSSI information from all the nodes. The program for sending and receiving the information packets was written and it was burned on Arduino MCU using Arduino 0022 software. Arduino 0022 is open source software which can be downloaded from internet and it acts as an interface for burning data into MCU board. The programming code was written and saved in ”.pde” format and was embedded into the Arduino UNO board. The programming included the ND (Node Discovery) AT command and was executed for sending and receiving of packets. Arduino board on the remote node sends the ND command to all the reference nodes in the range and these reference nodes receives the command and returns the information back to the remote node. The remote node then extracts the RSSI and node information from the packets and sends them back to the base station. Figure 3 shows the data flow executed in the Arduino UNO MCU.

The application for object tracking is coded in Matlab and the coded program has the capability of receiving data from the modules and also to return the location of mobile node. The object tracking algorithm makes use of the Arduino platform for location estimation application.

Indoor testing of zigbee

The calibration experiment was conducted room no. 209 at Building Sciences Block (BSB) in IIT Madras. The experimental test bed is shown in Figure 4. An laptop was used as the Base Station (BS) for the experiment. The Arduino Uno MCU was connected to all the Zigbee nodes and a programmed Zigbee was connected to the laptop which acted as the BS. The configured Zigbees were used to collect RSSI form all the nodes. The Software was designed only to monitor the RF from 802.15.4 radios propagating at a frequency of 2.4 GHz. The test bed illustrated in the figure is a 3-D structure of dimension 9 m (L) X 6.6 m (B) X 6.6 m (B) X 3.5 m (H). The locations where the Fingerprints are taken are indicated in the same figure. The centerpiece of our infrastructure is the Arduino Uno platform with AT Mega 328 microprocessor and IEEE 802.15.4 compliant Maxstream Xbee Zigbee radios.
The creation of Radiomap is the basis of Fingerprinting technique. Three reference nodes, one mobile node and a base station node were used for the creation of the Radiomap. The Base station node was connected to a Dell laptop and the data obtained was transferred to the computer. The Radiomap was created by executing the commands in the terminal of Linux operating system. The Mobile node was used to obtain the RSSI from all the three reference nodes and the same will be transferred to the base station node. The room was divided into a predefined number of grids and the mobile node was kept at all the grid locations to obtain the RSSI pattern at that particular location. A total of sixty to seventy readings were taken at each grid location. The RSSI values collected at the various locations was transferred and stored in the BS computer.

The most important step in the object tracking application is collection of data from all the sensors and it’s processing at the base station. The data obtained at the base station node is transferred to the system which runs the object tracking application. When the data arrives at the serial port, the application must capture it. First the mobile node transmits the beacons and the same will be received at the reference nodes. The reference node transmits the packet containing the RSSI values. The mobile node will send all the RSSI values to base station node which is then transferred to the BS system. The object tracking algorithm then calculates the position and returns it.

The testing of the module for location tracking was conducted in room no 209 of BSB and performance was noted. Three access points AP, AP2, AP3 were kept at three corners of the Room No 209 and the base station along with the BS node is kept at the centre of the room. The mobile node is made to move randomly inside the room and the beacons are emitted continuously. The emitted beacons are then received by the fixed nodes and the RSSI values are then returned to the BS. The BS calculates the location by comparing the RSSI database or the Radiomap with RSSI values transferred by the mobile node. The location tracking application developed in the work obtains the RSSI values from all the modules and then compares with Radiomap of the area to calculate the Euclidean distance. The application returns location of the mobile station and displays the location on a Graphical User Interface (GUI).

Outdoor validation of Zigbee

The acceptable performance of Zigbee in indoor environment led to testing its performance in outdoor environments. Performance of the modules were observed and analyzed at the outdoor space and it was compared with the ZigBee performance in indoor environments. The behaviour of RSSI in outdoor environment was predicted to be more satisfactory than the indoor environment due to the reduction in interference factor and less multipath effect. Outdoor analysis of Zigbee and its tracking system was experimented at a construction site inside IIT Madras. The reinforcement yard area was selected as test bed for study. The selected area was of di-
dimension 27 m X 17 m with a rebar bending bench at the centre of selected area. The reference nodes were fixed at three corners of the selected test bed. The base station node was connected to an Acer laptop. All three reference nodes were battery powered due to the absence of a permanent DC supply at the site. The mobile node was fixed on the helmet and was battery powered. Figure 7 shows the helmet mounted with mobile Zigbee node.

RADIOMAP for the selected test bed was obtained by collecting fingerprints of the area at selected locations. Seven locations were identified for taking the fingerprints. The seven locations cover the entire test bed so that movement of remote node inside any location of test bed can be tracked. RSSI’s required for creating fingerprints were obtained at all the seven locations and results were studied and analyzed. It was observed that the radio maps created for location estimation were exhibiting different patterns at different fingerprint locations. Therefore there was a difference in pattern of signatures created for outdoor tracking. Performance of reference nodes in sending RSSI values were observed at each fingerprint locations. Locations at which reference nodes displayed unacceptable behaviour were rejected and new location was selected for radiomap. Final locations which were selected for the creation of fingerprints are shown in the Figure 8. Mobile user with attached module was allowed to navigate inside the test bed and location estimation algorithm was executed. Movement of the remote node was successfully tracked by this application.

The system displayed good performance in tracking of mobile user in outdoor environment. Fluctuations in location estimation were observed to be less compared to indoor location tracking. Figure 9 displays location of mobile node when location estimation algorithm was executed.

Zigbee based location tracking system was tested for its performance by tracking the location of mobile user inside selected test bed. Mobile user with Xbee node was set up at various predefined positions and performance of location estimation system was analyzed. Initially the entire test bed was divided into seven grids and fingerprint location for each grid was selected as the centre of the grid. Radiomap for the entire area was created and embedded inside the location estimation algorithm. The mobile node was then allowed to move and the developed location estimation system was tested for its performance of tracking mobile node when it moves from one location to another. Accuracy and consistency of system in tracking position were tested through the experiment. Mobile node was given a pause in movement at every one metre from each fingerprinting location and position displayed by location estimating algorithm was observed. Entire test bed was tested with mobile node for studying the performance of Xbee tracking system. From performance tests, it was inferred that location estimation system developed on the basis of Zigbee protocol was having an accuracy of 3 m to 5 m. Figure 10 displays the points where the system behaved erroneous.
A total of 217 points were selected for testing of location estimating system out of which 178 points displayed correct positions. There were only 39 erroneous points in the entire set. From the study, it was observed that location estimating system developed on the basis of Zigbee displayed an accuracy of 82%. The accuracy of 82% was acceptable and test proved successful. Table 2 displays total points selected for each position and error at each location. It was also observed that the system took some time to stabilize and update its new location, when it moved from one location to another. Time gap for location updating was observed to be 15-20 seconds.

Location estimation application in this work was limited to small test bed and network. System developed for this project was designed for future expansion of the tracking network. Mobile node used for this project was programmed to consider all the nodes in the range. ATND command coded in mobile node was capable of obtaining information from all nodes available in its range. Arduino sends the received information from all nodes to the base station in a separate packet containing node information and RSSI. Packet send by mobile node specifies the length of entire packet and this length forms the check for location estimation algorithm. When algorithm is triggered for location estimation, it checks for RSSI from all nodes available in the network. Positioning will be carried out only if length of packet received from mobile node matches with number of RSSI values processed inside location estimating algorithm. The algorithm is already designed for accommodating additional nodes and hence there is significant potential for expansion of network to a large test bed.

Table 2. Accuracy of system at test locations in actual construction site

<table>
<thead>
<tr>
<th>Location</th>
<th>Total points</th>
<th>Correct results</th>
<th>Erroneous results</th>
<th>% error</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>32</td>
<td>26</td>
<td>6</td>
<td>19%</td>
<td>81%</td>
</tr>
<tr>
<td>Position 2</td>
<td>36</td>
<td>21</td>
<td>9</td>
<td>29%</td>
<td>74%</td>
</tr>
<tr>
<td>Position 3</td>
<td>26</td>
<td>21</td>
<td>5</td>
<td>19%</td>
<td>81%</td>
</tr>
<tr>
<td>Position 4</td>
<td>28</td>
<td>24</td>
<td>4</td>
<td>14%</td>
<td>86%</td>
</tr>
<tr>
<td>Position 5</td>
<td>33</td>
<td>27</td>
<td>6</td>
<td>19%</td>
<td>82%</td>
</tr>
<tr>
<td>Position 6</td>
<td>30</td>
<td>23</td>
<td>2</td>
<td>7%</td>
<td>93%</td>
</tr>
<tr>
<td>Position 7</td>
<td>33</td>
<td>25</td>
<td>7</td>
<td>21%</td>
<td>79%</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>217</td>
<td>178</td>
<td>39</td>
<td>18%</td>
<td>82%</td>
</tr>
</tbody>
</table>

The tracking system developed on the basis of Zigbee exhibited good performance in tracking position of mobile node inside room no. 209 of BSB, IIT Madras. The location was estimated with an accuracy of 3-5 m and GUI displayed position of the mobile user on the map. System exhibited fluctuations in the position of the user and location display fluctuated in the map of GUI. Close spacing of the fingerprints, interference and multipath effect may be reasons for the fluctuation in location estimation. The performance of the system was studied in actual construction site and analysis was done. From site validation of developed tracking tool, it was observed that positioning system based on Zigbee protocol have significant potential for application in both inside and outside environment. Zigbee based system can be a better low cost tracking tool for positioning of labors in areas where GPS does not work. System showed acceptable accuracy in both indoor and outdoor space with comparatively more precision at outdoor environments. Scalability of ZigBee networks was also checked and proved to be successful.

**SUMMARY AND CONCLUSIONS**

The research on positioning of human resources using Zigbee networks lead to following conclusions

- From the study, it can be observed that Zigbee protocol on IEEE 802.15.4 infrastructure has significant potential in tracking of labors. The location estimating system developed on Zigbee protocol exhibited good performance in tracking of labors in both inside and outside environments. Hence it can be concluded that Zigbee has potential scope in the area of positioning of labor and construction resources.

- Due to the ability of Zigbee modules in tapping RSSI from sending and receiving packets, it was observed that fingerprinting technique based on RSSI was most suitable for the study. It was observed that the Xbee modules based on Zigbee protocol was successful in tapping RSSI from different nodes without much variation. Hence it can be concluded that location tracking using Xbee module and Fingerprinting technique is very effective and exhibits acceptable accuracy. Location tracking using fingerprinting technique displayed good and acceptable results without complex infrastructure and costly equipment’s.

- The study conducted in actual construction sites proved satisfactory and exhibited good accuracy. Results from various experiments proved that system is effective in both indoor and outdoor environments. It was observed that the accuracy
of developed location estimation system was 82% and is acceptable.

The research in this thesis provides a basis for ground work for the future study of efficient design of positioning systems using wireless sensor networks based on Zigbee protocols. The RSSI based location estimation systems has limitations. The large variation of RSSI with time and material movement has a significant impact on positioning and this should be taken into consideration. The fluctuation of estimated location due to the variation of RSSI and its control using smoothening and filtering algorithms may reduce the large variation in RSSI. The power consumption of the modules is still an issue and research can be carried out to minimize the power consumption. The network and test area considered in this work were confined. The network can be expanded to a large area test bed and its effectiveness in productivity analysis can be studied.

References

640
An optimized operation algorithm for twin or multi-cage lift systems for high-rise construction sites

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Purpose
The objective of this study is to develop an algorithm which can increase productivity of lift operation on temporary twin-cage and multi-cage lifts for construction sites. The algorithm is developed for optimizing operation efficiency at high-rise construction sites. Moreover, it is expected that the algorithm can reduce working hours and traffic queues through operation optimization.

Method
The developed algorithm can optimize lift operation time by using a lifting cycle-estimating method which is generated based on the fundamental concerns when lift scheduling is planned. Lifting cycle-estimation is a vital part for an arithmetic computation based on lift selection algorithm which controls factors such as distance between each lifts, among passengers, and distances among lifts according to moving direction.

Results & Discussion
We carried out surveys and conducted interviews with mechanical and construction professionals to analyse fundamental considerations of material lifting operation planning. We extracted the weight of each of the relevant factors. Based on the weight of factors, we set the lifting cycle-estimate suitable for high-rise buildings. The optimized operating algorithm is extracted through lifting cycle-estimates. Finally, we propose the prototype of an interface that is embedded into the lift with the optimized operating algorithm.

Keywords: optimization algorithm, operation algorithm, lift car, operating cycle-estimate

INTRODUCTION
Numerous super high-rise buildings have been built around the world, and many more are planned to be built that are often over 100 stories high1. Larger, higher buildings are subject to more restrictions in terms of construction planning and operation.2 Among them, movement management of materials and labors is closely related to productivity of super-high rise construction, and its importance grows as the buildings become higher. Currently, at super high-rise construction sites, an experienced site supervisor and operator manage the hoist operation for movement of materials and labors.3 This lowers efficiency of vertical movement in operating construction hoist. The lift user’s queue time increases in higher buildings. Several construction hoists are planned and built in constructing super high-rise buildings over 100 stories. Unlike elevators installed at the core of the structure, construction hoists are built outside the building, upon the mast, and they are hard to control in an integrated manner. Often construction hoists are operated redundantly, delaying construction schedule in a large project. Given these circumstances, this study conducts a simulation on construction hoist operation, explores how to improve movement of materials and labors in super high-rise construction by developing optimized operation algorithm. The simulation results are assessed based on the cycle time of daily unit work processes according to lifting cycle time calculation (Cho, 2010).

RESEARCH TREND (LITERATURE REVIEWS)
Sacks et al. developed an automated lifting equipment monitoring system (Sacks et al, 2005).4 Cho et al. conducted a study on construction hoist operation planning in terms of lifting height and loading (2010, 2011). Further, Shin proposed optimal operation of temporary construction hoists in a super high-rise building based on simulation and genetic algorithm. Before them, most studies focused on the use of tower crane or mobile crane, and other studies on construction hoist tended to emphasize lifting planning rather than lifting operation.

As super high-rise construction becomes more popular in Korea, there is a growing need for a systematic construction planning and site management. The government and private corporations are actively undertaking studies on operation planning of construction hoists and tower crane lifting. Kim et al. studied how to calculate a number of necessary construction hoists at super high-rise construction site (2008)5, and Shin et al. proposed a construction hoist movement planning model for super high-rise construction (2010). Cho et al. (2011) proposed an algorithm that calculates lifting time in consideration of acceleration and deceleration capability of construction hoists (2011).6 While there are many stud-
ies on construction hoist planning, few have been conducted on the system, management and algorithm of construction hoist operation, with no empirical analysis.

**The Concept of Research**

**Unmanned Smart Construction Hoist**

This study aims to advance construction technology of super high-rise buildings, with a goal to optimize vertical lifting of materials and labors in erecting a super high-rise building. In this study, the control server was connected to construction hoist installed at each mast and to the Zigbee wireless network system. (Fig. 1) Based on the data received from each construction hoist, the study designed a system to give an operating order. Each construction hoist sends real-time data on lifting speed, direction and present load to the control server. The server collects the data, selects the optimum lift and sends an operating order. The focus is on proposing a model that controls many construction hoists at once and operates them, as a preliminary step to develop unmanned smart lift.

![Fig 1. Concept of Unmanned Smart Construction hoist](image)

**Twin or Multi-cage Hoist Operation System**

The highest building in the world, Burj Khalifa, used 17 construction hoists during the construction. Each mast is put in different places, depending on the site conditions, and currently, work schedule is made to prioritize the order of materials and labors for integrated management. However, with predetermined schedule, it is hard to flexibly respond to the unexpected situations at the site. Thus, an integrated control system is needed to manage construction hoist operation.

The algorithm flow basically depends on elevator distribution algorithm for labor movement (Fig. 2). The difference is that the control server analyzes condition of the construction hoists by receiving operation data from the Zigbee network.

![Fig 2. Algorithm Flow of Unmanned Smart Construction hoist](image)

**Embedded Construction Hoist Information**

The control server examines algorithm to select the optimum construction hoist, requesting the following data:

1. Velocity of Lift car
2. Position of Lift car
3. Direction of Lift car
4. Real-time available transportation capacity

In this study, a simulation was conducted for the operation information system that manages four construction hoists. Figure 3 illustrates a display device that shows detailed information and operation status of construction hoists on the control server.
Each construction hoist requires information collecting device to send four sets of real-time data to the Zigbee wireless network as shown above. The double sensor type position detector provides information on the direction and position of a construction hoist. In the detector, two proximity sensors read grooves of the internal gear to detect upward or downward movement of a construction hoist, and examines rotation of the rack gear to calculate the velocity.

Evaluation Method for optimum car selecting

The construction hoist information collected by the sensors is transmitted to the control server through the Zigbee network. The information provides a basis for the algorithm to select optimum construction hoist when the next call comes in. Figure 5 describes the selection flow, how it eliminates unsuitable construction hoists by lift direction, present location and load capacity. In selecting optimum construction hoist, a primary consideration is the present load capacity; if the capacity is already full, the hoist is instantly excluded. The lift direction and the direction to the call floor are considered in terms of minimizing the movement. Third, travel time is calculated for the remaining hoists to select the optimum construction hoist that minimizes queue time of materials and labors.

The pseudo code below shows an algorithm system that yields the order of lift car selection based on cycle time calculation. First round of filtering is done between step 1 and 9, considering the present load capacity and accordance of the direction. Second round of filtering is done between step 10 and 17 to select the hoist with minimum travel time. After the first round of filtering, travel time is calculated for the remaining hoists; the calculation formula are different for hoists that are presently operating and hoists that are idle at the moment. It is because time for power supply, acceleration and reduction should be considered. For example, acceleration time needs not be considered for currently operating hoists.
hoist; only reduction speed time matters at time of arrival.

**Pseudocode for hoist Selection**

1. \( i \leftarrow \text{code number of each construction hoist} \)
2. \( \text{create arrays Hoist[1 ... 4]} \)
3. \( \text{Hoist[i]} = -1 \)
4. \( \text{for } i \leftarrow 1 \text{ to } 4 \)
5. \( \text{do if } W_i \leq W_{M4} \times 0.8 \)
6. \( \text{if } n - n_i < 0, k_i = 0 \text{ or } 2 \)
7. \( \text{else if } n - n_i > 0, k_i = 0 \text{ or } 1 \)
8. \( \text{then } \text{Hoist[i]} = 0 \)
9. \( \text{return } i \text{ that hoist arrays value is } 0 \)
10. \( \text{for } i \leftarrow 1 \text{ to } 4 \)
11. \( \text{if } \text{Hoist[i]} = 0 \)
12. \( \text{if } k_i \leftarrow 0 \)
13. \( \text{do } T_i = \left( (n - n_i - h)/V_i \right) + S_1 + S_2 \)
14. \( \text{else } k \leftarrow 1 \text{ or } k \leftarrow 2 \)
15. \( \text{do } T_i = (n - n_i - h)/V_2 \)
16. \( \text{let } z \text{ be the smallest value in } T_i \)
17. \( \text{return } i \text{ that is } T_i = z \)

Here,

- \( i \): Code number of each construction hoist
- \( W_i \): Weight of each construction hoist
- \( W_{M4} \): Maximum capacity of each construction hoist
- \( n \): Call floor
- \( n_i \): Position of each construction hoist
- \( h \): Distance for construction hoist acceleration and reduction
- \( k_i \): Direction of previous call of each construction hoist
- \( T_i \): Lifting time at operation speed
- \( S_1 \): acceleration time
- \( S_2 \): reduction time

Travel time for arrival was calculated according to the formula for the simulation method for construction hoist operation plan (Cho et al., 2009).

**SIMULATION METHOD**

**Simulation Condition and Model**

The following hypotheses were adopted to verify workability of the proposed twin or multi-cage operation algorithm.

First, except for the ground floor, all floors have a same floor height.

Second, the building has two masts and four construction hoists.

Third, when a floor call comes in and a selected construction hoist begins to move, other hoists do not respond.

Fourth, rated velocity, acceleration and reduction time are preset for each type of construction hoist. More specifically, velocity of construction hoist A and D is 100m/min; their acceleration and reduction capacity are 0.60m/sec² and 0.57m/sec² respectively.

For construction hoist B and C, the velocity is 70m/min, and their acceleration and reduction capacity are 0.55m/sec² and 0.53m/sec² respectively. In other words, operation speed and acceleration speed are given as constant, not variables, in an algorithm for optimum construction hoist selection.

Fifth, considering that a construction hoist moves materials and labors at the same time, algorithm process identifies construction hoists that are operating over 80% of the load capacity.

Sixth, since this study deals with lifting operation rather than lifting planning, the optimum travel route will be to assign a construction hoist for materials and labors in the shortest time.

An analysis was made on the lifting operating simulation to examine reliability of the optimum construction hoist selection algorithm according to the six aforementioned conditions.

**Simulation of Optimum construction hoist Selection Algorithm**

The study conducted simulation to measure lifting cycle time of the materials, and the result was compared to the manual construction hoist operation. Currently, an operator judges the floor calls, and sometimes multiple hoists are operated redundantly, lacking information on their status. This happens because an operator merely responds to floor calls without considering the overall management of the lifting operation.

![Fig 6. Difference between As-is system and To-be system](image-url)
The proposed algorithm for selection of optimum unmanned smart hoist uses a formula to decide travel route that reduces total cycle time, and it can solve the problem of redundant operation. The lifting model was based on the lifting cycle time of four construction hoists; assuming that the hoists are in operation, current position, direction, velocity, weight and call order were randomly assigned to each hoist.

Then, floor calls were generated at random floors at a regular interval to calculate lifting cycle time for both the current system and the proposed algorithm for optimum construction hoist selection.

**Table 1 Simulation Conditions**

<table>
<thead>
<tr>
<th>Loading/Unloading Time</th>
<th>0.1 min</th>
<th>Door Open/Close Time</th>
<th>0.05 min</th>
<th>Total floor</th>
<th>30</th>
<th>Number of Hoist</th>
<th>4</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Hoist Model</th>
<th>Hoist A</th>
<th>Hoist B</th>
<th>Hoist C</th>
<th>Hoist D</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Capacity</th>
<th>3000kg</th>
<th>2000kg</th>
<th>2000kg</th>
<th>3000kg</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Weight</th>
<th>600kg</th>
<th>1000kg</th>
<th>800kg</th>
<th>0kg</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Velocity</th>
<th>100 m/min</th>
<th>70 m/min</th>
<th>70 m/min</th>
<th>0 m/min</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Direction</th>
<th>↑</th>
<th>↓</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Floor</th>
<th>9</th>
<th>27</th>
<th>23</th>
<th>5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Call Floor</th>
<th>15</th>
<th>21</th>
<th>9</th>
<th>-</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Target Floor</th>
<th>1</th>
<th>1</th>
<th>25</th>
<th>-</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Lifting Priority</th>
<th>Call Floor</th>
<th>Floor call Time</th>
<th>Target Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>0:00</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>0:30</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>1:00</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>29</td>
<td>1:30</td>
<td>13</td>
</tr>
</tbody>
</table>

Cycle time was calculated based on the cycle time calculation formula (Cho et al, 2010) 

**Simulation Result and Analysis**

As a result in simulation via simulation model table 1, cycle time data of two masts is table 2 and table 3. When 4 hoists in 2 masts are operated under twin or multi-cage algorithm, in following table2 and 3, every possible duplicated operation can be eliminated. Black marked part means selection of hoist at floor call is occurred.

When 4th floor calls are occurred through simulation condition of table 1. The time spending for total lifting is 154.25sec considering material loading time and door-open time.

<table>
<thead>
<tr>
<th>Event</th>
<th>DIRECTION (↑/↓)</th>
<th>POSITION (FLOOR)</th>
<th>DIRECTION (↑/↓)</th>
<th>POSITION (FLOOR)</th>
<th>TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOOR CALL A</td>
<td>↑</td>
<td>9</td>
<td>↓</td>
<td>27</td>
<td>0.00</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL A</td>
<td>-</td>
<td>15</td>
<td>-</td>
<td>21</td>
<td>19.62</td>
</tr>
<tr>
<td>FLOOR CALL B</td>
<td>↓</td>
<td>12</td>
<td>↓</td>
<td>20</td>
<td>30.00</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL B</td>
<td>↓</td>
<td>3</td>
<td>↓</td>
<td>14</td>
<td>49.70</td>
</tr>
<tr>
<td>FLOOR CALL C</td>
<td>-</td>
<td>1</td>
<td>↓</td>
<td>11</td>
<td>60.00</td>
</tr>
<tr>
<td>FLOOR CALL D</td>
<td>↑</td>
<td>11</td>
<td>↓</td>
<td>2</td>
<td>90.00</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL C</td>
<td>-</td>
<td>17</td>
<td>-</td>
<td>1</td>
<td>104.81</td>
</tr>
<tr>
<td>FINISH EVENTS</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>1</td>
<td>154.25</td>
</tr>
</tbody>
</table>

Table 2 Operation Cycle Time <Mast 1>
Table 3 Operation Cycle Time <Mast 2>

<table>
<thead>
<tr>
<th>EVENT</th>
<th>HOIST C</th>
<th>HOIST D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIRECTION (↑/↓)</td>
<td>POSITION (FLOOR)</td>
</tr>
<tr>
<td>FLOOR CALL A</td>
<td>↓</td>
<td>23</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL A</td>
<td>↓</td>
<td>16</td>
</tr>
<tr>
<td>FLOOR CALL B</td>
<td>↓</td>
<td>12</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL B</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>FLOOR CALL C</td>
<td>↓</td>
<td>6</td>
</tr>
<tr>
<td>FLOOR CALL D</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>ARRIVE FLOOR CALL C</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>FINISH EVENTS</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

CONCLUSION AND FURTHER STUDY

In this study, we proposed an unmanned smart lifting system and devised an optimum construction hoist selection algorithm on twin or multi-cage. And estimate the productivity of proposed system through simulation method. Proposed algorithm is considering hoist velocity, direction, position and weight capacity. Using optimum construction hoist selection algorithm process, eliminate all the duplicated call operation and minimize the queue time of materials and labor.

But, the detailed mechanic design of this system should be subjoined. Through searching the limitation factors of wireless network in construction site, we can consider optimization of information transmission between each construction hoist and central control server.

ACKNOWLEDGEMENT

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References

An integrated automatic wall concreting system

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**INTRODUCTION**

**Ja-wa** (ja-wa, or unilateral application - wandering automation system (in Polish: system jednostronnej aplikacji – wędrującym automatem) is a representative of the technology which envisages automation of some processes carried out at the construction site, when building sandwich walls. At the same time, ja-wa integrates the problem of adaptation of the design of the building in the area of automatic preparation of organisational and execution management solutions, as well as computer control of the auto manipulator erecting the walls, together with control of the progress of works, naturally including complex mechanisation of auxiliary works.

In typical solutions applied, on the structural layer of the load-carrying wall, performed in the first instance, insulation, protective, and other layers are installed. At ja-wa, the order of wall construction is reverse. First, the e.g. façade siding or thermal insulation layer, constituting light unilateral formwork, is stabilised. Next, the structural part is performed. The material is jetted in layers, with "wet-on-wet" method, allowing for their good monolithic nature. Material application at the appropriate intervals also allows for the use of growing strength of the layers made earlier to transport loads from the layers placed later. This allows for making of an even massive wall with little load on the formwork. The main ja-wa equipment applied at wall erection is the automatic computer-controlled manipulator together with specialist rail device. The mobile rail device is a light scaffolding of assembly structure, which as a disassembled kit can be subject to reloading, warehousing and transport. The device features rail for the automatic manipulator, and serves to stabilise the light unilateral formwork, e.g. in the form of target thermal insulation layer of the wall. While riding on the device rail, the manipulator moves the nozzle that applies the material. The material prepared in the mixer-pump is pumped via the pipe to the application nozzle that remains in a casing which at the same time secures against dusting and losses, on the one hand, and shapes the surface, on the other. The control of the manipulator and the pump is performed by the computer, according to the programmed scope and method of the works.

At present, one can observe advanced works on automated construction robot systems for construction of entire buildings, as well as their complexes. The systems integrate the following functions: work organisation planning, operating time control, material consumption and quality of the works. Examples of the developments include the following systems. AMURAD (AutoMatic Up-Rising Construction by ADvance Technique*) features temporary structures. The systems integrate the following functions: work organisation planning, operating time control, material consumption and quality of the works. Examples of the developments include the following systems. SMART System (Shimizu Corporation**) is a completely automated system, where after the completion of the top floor – first, automatic servos push the entire storey upwards, and the following lower floor is erected in its place, etc. On the storeys erected, finishing works are performed. SMART System features temporary rood equipped with transport devices and a machine for erection of structural steel frames and casing walls of the building, with automatic welding and control systems. The automatic mechanism raises...
the roof upwards using special lattice masts. ABSC (Automated Building System Construction), which is a fully automated system for construction of steel skeletal buildings, uses the working platform that rises, but is supported on previously completed storeys. A concept for building construction that has development potential is CC (Contour Crafting), using an automatic gantry that moves on rails and features a nozzle laying and forming the material, as well as a device for assembly of reinforcement and installations. When the nozzle moves, first, the curved or straight edges of the walls are formed, which, as lost formwork, is filled with the material during the next cycle of nozzle move.
The systems envisage automatic construction of entire buildings, usually high buildings. As a consequence, such method of construction of entire buildings in the 1:1 scale requires development of certain automatic factories that carry out production in a large space, but also high at the site. Due to the need for precise movements of specialised gantries, with a set of adjusted cooperating equipment, their weights are significant, reaching even beyond several hundred tonnes. These area also very expensive solutions. The ja-wa system naturally does not meet the precondition of complex automation, but it also basically facilitates work with much lower outlays. This study covers the general characteristics of ja-wa and the equipment applied, together with execution of an exemplary wall using the automation manipulator moving on systemic rail.

INTEGRATION OF PLANNING, EXECUTION AND CONTROL ISSUES
A distinct feature of automated systems for building construction is the general use of IT technologies. Similarly in ja-wa, when using databases and knowledge, there is automatic integration of automatically performed computer calculations and analysis in the area of documentation generation upon direct adaptation of the building design, developed in typical software, e.g. AutoCAD, determining outlays on labour, materials and equipment operation, as well as financial and environmental outlays (in the context of building life), as well as management planning, work organisation and transport logistics, site management, as well as the schedules for preparations and execution of the task. There is also an automatic management system comprising databases of identified production and material resources, preparation of prefabricated items, transport and execution of works at the site, as well as sales, functioning online according to the principle of on-going monitoring ‘in situ’, which is used for data processing at the centre and for decision-making at the decision-maker’s site. Tele-transmission allows for on-going cooperation of the centre with continuous research and determination of the most favourable current solutions, appropriate for the currently occurring conditions at the site for work execution by the manipulator, with complex use of the computer for controlling robot operation, namely its launch, work control, as well as stoppage and monitoring, safety control and quality of the execution.

Below is the selected fragment of analyses related to environmental outlays. Due to incomplete information on the value of materials and products which carry the prices, an important issue refers to the analyses considering the environmental impact of the building during its entire life cycle, namely sozo-economic analyses. Such analyses, apart from cash flow, consider environmental outlays from the moment of planning the building, through programming and designing, as well as construction of the building, including its long-term use, with significant outlays related to e.g. heating/air-conditioning, including renovations, modernisations, and finally its physical elimination. Naturally, this includes the entire sphere of impact, material and equipment used in this period, the prior production of which was often also related to high environmental costs.

In reference to a building facility, the sozo-economic model of analysis can be formulated as follows, [20]:

\[ B_1 + B_e = \frac{\sum_{t=0}^{n} CIF_t - COF_t}{(1+k)^t} - \frac{\sum_{t=0}^{n} \omega e_t}{(1+k)^t} \geq 0, \]

- Conditions: 
  \[ B_1, CIF_t, COF_t \geq 0, \]

where:
- updated as of present with discount rate at level \( k \):
  \[ B_1 \] - economic benefits for the entity due to investment (investing benefits), PLN,
  \[ B_e \] - environmental benefits, PLN,
- cash flow from the business in year including:
  \[ CIF_t \] - cash inflow, PLN,
  \[ COF_t \] - cash outflow, PLN,
  \[ \omega e_t \] - non-assessed environmental outlays, PLN,
- are determined for the full life cycle of the building, from the first plan, corresponding to commencement of action in year \( t = 0 \), throughout the period of building presence, until the completion of the last control activity in year \( t = n \).

Environmental benefits \( B_e \) considered represent the value of public welfare, as value of their existence "as such", which is lost in the environment due to construction of the building, including materials and equipment used for its construction and during use. The value of existence is described as follows: “Even if a particular unit is not a consumer of environmental resources..., it may attach specific importance to its existence and existing welfare. It may also derive satisfaction from the very fact of existence of such welfare and their availability to people living at present and in the future,” [22]. It is a value that results from the very fact of existence of the environment in its natural state, e.g. of a mountain without its defect caused by collection of a mineral to produce cement, or steel.

In turn, non-assessed environmental outlays \( \omega e_t \) represent the value of external effects caused by the building facility, and which are not considered in

\[ \text{648} \]
cash flows CIF<sub>t</sub> and COF<sub>t</sub>. Non-assessed environmental outlays oet due to raw materials consumption constitute the value of the irrevocably collected mineral with distortion to the natural state of the environment, which is “usually neglected”. It seems that for an objective complex assessment of the solutions, similar extended analyses are necessary.

**List of Equipment**

The main equipment ensuring partial automation of the wall construction processes in ja-wa includes: systemic rail and automatic manipulator, as well as dosing-mixing unit with a pump, and material tank. Systemic rail device features a rail for moving automatic manipulator along the walls constructed, Fig. 1.

The device is characterised with high mobility. The complete device is disassembled into two flat elements which, together with the manipulator, are entirely subject to reloading and transport. The device is a type of systemic light scaffolding with fixed, jointed and sliding connections of particular parts. This allows, depending on the needs, for quick assembly or disassembly of entire segments corresponding to two neighbouring walls in the building constructed (without the need for disassembly into individual parts).

At the site, the device is transported and set with the crane of the transporting vehicle or with a crane at the site. Elements: 1.1 – are opened, 1.2 – slided and set appropriately to the form of walls performed. The device also serves for initial stabilisation of unilateral lost formwork - 1.3, e.g. in the form of target thermal insulation layer of the wall, which is kept in the planned position by top sprags - 1.4 stabilised on the poles of systemic scaffolding.

The automatic manipulator, namely robot with inbuilt computer and controller together with the applicator, serves for jetting the material, and possibly for shaping the surface of the layer made.

The controller, according to the programme corresponding to the design of the building constructed, ensures robot’s passes and shift of the applicator, according to the route required, with the consecutively placed layers and with finishing of the wall surface. According to the programme, the computer monitors the course of the process, controls and analyses the times of material preparation and jetting in particular layers and places of the wall constructed.

The manipulator with inbuilt computer and controller - 1.5, moves on the rail of the rail device - 1.6, along the wall constructed, while upwards and downwards within the extent of the storey height, on its own vertical frame - 1.7. Material ejector with casing - 1.8 is placed on the applicator plate. The casing protects against material losses, and the texturizing element serves for possible levelling of the layers and for surface finishing.

The dosing-mixing unit with a pump and the material tank are placed at the wall opposite to the place from where the manipulator begins jetting (this allows for shortening the feed pipe by half). The unit collects components from the tank and, after preparation, pumps them to the ejector.

**Example of Wall Construction**

In ja-wa, with ‘reverse’ order of the works, e.g. thermal insulation layer is set as the first element, Fig. 2. Elements - 2.1, from thermal insulation material are of the storey height (with floor thickness) and of modular length. They feature locks - 2.2, to improve the joint, and at the same time ensuring good facing of the surface of neighbouring elements. From the external, façade side, in the glue layer - 2.3, the reinforcement mesh is embedded - 2.4, together with overlaps - 2.5, to bond the joints. On the internal surface of elements 2.1, a thin glued adhesive layer is made - 2.6. The elements, acting as light unilateral lost formwork, may feature profiled groves on the internal side, with appropriate cross-section, for the purpose of forming poles in them - 2.7, ring beams, and possibly ribs to stiffen the wall. Elements prepared in the auxiliary production plant have lashing points - 2.8, passing across the entire thickness, for the purpose of anchoring the entire thermal insulation layer in the structural layer performed later. In the lashing point terminals, there are sockets for stabilisation and gauging of the structural reinforcement of the wall - 2.9 (which, after installation, additionally stiffen the forming element). Stabilisation of the elements with sprags to the poles of the systemic rail device ensures their precise gauging against the robot’s driving rails (cf. Fig. 1).
Material laying
Material is laid and thickened by jetting, using the energy of the plume of high-velocity particles. The device begins jetting from the centre of the wall opposite against the dosing-mixing unit with a pump and material tank. This allows for reducing the pipe length to the half of the wall made (unfolded). When building light walls with bearing, skeletal structure and a thin wall between the poles (cf. Fig. 2), Poles and ring beams (possibly ribs) are made first. The material is placed in layers. Jetting is performed e.g. from the bottom of the pole vertically upwards, and then the ring beam horizontally, next pole vertically, down and upwards, ring beam, etc. At the corner pole, the ejector turns at the angle of 45° and jets the material at the pass downwards, next the manipulator moves to the neighbouring wall, sets the ejector at the angle of 45° and ejects the layer at the same corner pole, moving the ejector upwards, further on again moving to the ring beam, pole, and until the end of the wall. Similar jetting of the layer in the ring beam is observed in the return pass. As a result, after each complete cycle (pass and back) of the manipulator, two layers of the material are placed. Fig. 1 presents a fragment of the ejector route and elements of the programme for the applied PLC controller of series VersaMax Micro, type IC200UDR064-AB.
Fig. 4. Fragments of the ejector route when performing poles and ring beams in wall corners and elements of the programme for PLC series VersaMax Micro, type IC200UDR064-AB, description in the text.

The material for the entire wall surface is also jetted in layers, in the form of belts with the height of the storey. After completion of the first belt, the robot moves by its width and places the next belt, again moves in the same direction, places another belt, etc., until the last belt connecting to the first belt of the layer is made (or until the entire wall is covered with a layer from the beginning to the end). The robot returns to the start place in an idle run. It begins laying the next layer, starting from the place of the first belt (previously made) with the shift by half of the width (of the belt), observing the same order of laying as in the case of the belts in the first layer. The first layer, adhesive one, is the thinnest, of 0.1 ÷ 0.3 cm thickness, the next of approx. 1.5 cm, while the last, facing layer – of 0.7 cm, with the surface smoothed or with external texture made. Also, a painting layer can be placed.

CONCLUSION
Characteristic features of ja-wa include the following:
- integration and facilitation of executive documentation preparation, with calculations and analysis made automatically by the computer according to the developed programme, based on direct adaptation of the building design, developed in e.g. AutoCAD, for the case of well-known and described limitations upon work performance by the automatic manipulator, determining labour, material and equipment operation, as well as financial outlays (in the context of building life cycle and environmental impact), as well as planning of management, work organisation and site management, together with the schedule for preparations and task execution.
- significant use of IT technologies, including for performance of continuous research and determination of the most favourable current solutions, appropriate for the currently occurring conditions at the site for work execution by the manipulator, with complex use of the computer for controlling robot operation, namely its launch, work control, as well as stoppage and monitoring, safety control and quality of the execution.
- The solution is characterised with little involvement of technical means, namely small weight, and low capital intensity of the equipment, in the form of the following computer-controlled equipment: light automatic manipulator, which "wanders" along the systemic rail device and dosing-mixing unit with a pump.
- The concept of a robot "wandering" along the mobile rail device ensures precise execution of activities at a large space without the need to apply long booms and massive stabilising structures, characterised with high material and capital intensity.
- The reverse order of the works allows for performance of a complete wall with lower outlays on labour, materials and equipment operation, as the complete wall is performed in one technological line, more favourably than in standard solutions, when first the structural layer is made, while in another cycle, i.a. the thermal and protective layers are performed, with the need to apply another external scaffolding.
- man is favourably freed of physical work and deals with equipment operation, with labour reduction to programme launch.

References
Static compensation ZMP algorithm preventing tips-over of a tele-operation excavator

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Purpose Research on tele-operated excavators that protect the operator from the risk of tip-over excavators in hazardous working areas has increased in popularity. The tele-operated excavator is able to protect workers from risks in hazardous working areas, but the operator cannot directly access the tip-over information from the tele-operated excavator. We propose the static compensation ZMP (Zero Moment Point) algorithm for preventing excavator tip-overs.

Method Firstly, kinematic and kinetic analysis of the excavator was performed. Secondly, static compensation ZMP algorithm, which uses ZMP algorithm to determine gait stability of a biped walking robot, was developed to prevent tips-over of tele-operation excavator. Static compensation ZMP algorithm minimizes ZMP-error due to rapidly changing excavator acceleration using the center of gravity through a static compensation algorithm. Finally, the result of the proposed algorithm is simulated by RecurDyn model with Matlab Simulink co-simulation method.

Results & Discussion In the simulation result ZMP has been compared to static compensation ZMP-algorithm using an excavator dynamic model. From these results we see that the ZMP value is bigger than the static compensation ZMP. This means that the general ZMP is disturbed due to rapidly changing excavator acceleration. This problem is minimized by the static compensation ZMP-algorithm.

Keywords: excavator, tips-over, ZMP (Zero Moment Point), CoG(Center of Gravity)

INTRODUCTION In most of construction and civil engineering works, hydraulic excavators are used. Hydraulic excavators can apply to diverse kinds of works, and compared with other equipment items, they offer high economic value and universality and thus continue to be widely used. For instance, excavators represent over 30% of heavy equipment items that are recently being used in construction and civil engineering work sites. Excavators can apply to diverse works, and are heavily used in dangerous areas compared with other heavy equipment items. In dangerous areas, which have unconstructed environments, workers are always exposed to dangerous accidents. In actuality, most of accidents in construction works and civil engineering are involved with excavators. To address these problems, research on tele-operation excavators is recently being conducted actively to secure the safety of workers in dangerous areas. The tele-operation excavators are operated by workers at a short distance with visual confirmation. This can secure the safety of workers, but limits the work’s information on the excavator. Notably, the worker cannot feel the decline of the excavator, and thus can hardly expect the tips-over of the excavator. To address these problems, research is being actively conducted to sense the tips-over of the excavator. The research methods for sensing the tips-over of the excavator are classified into the static method designed to trace the CoG(Center of Gravity) of the excavator and expect the tips-over, and into the ZMP (Zero Moment Point) method which considers moment.

First, the static method, which uses the CoG of excavator, is to trace the excavator's CoM(Center of Mass) changing to its behaviors and to confirm whether the excavator is deviated from the support polygon. However, if the excavator experiences a sudden behavior change, kinematic causes cannot be considered and thus errors are created between the CoM and the calculated CoG. To address these problems, research is being conducted to apply ZMP - which is used to assess the behavioral stability in biped walking robots - to excavators. The ZMP algorithm can consider the kinetic features associated with a sudden excavator behavior in tracing CoM, thus securing more accurate traceability than the method of tracing CoG. However, excavators, which use high-power hydraulic cylinders, generate big shocks in the driving unit when it experiences behavioral changes, compared with biped walking robots. This shock can be seen as force, which means a sudden acceleration change.

The conventional ZMP algorithm, which uses each link’s CoM(Center of Mass) acceleration in the Cartesian coordinate space in tracing the entire excavator CoM, very sensitively responds to acceleration changes. Thus, the existing ZMP algorithm - compared with when it is used in biped walking robots -

652
would create great accuracy error in hydraulic excavators which experience sudden acceleration changes.

To address these problems, this study proposes the static compensation ZMP algorithm by which the static method designed for tracing CoG less affected by sudden acceleration changes is compensated with ZMP algorithm so to remain robust to acceleration changes associated with shocks.

To verify the proposed algorithm, the kinetic analysis tool RecurDyn is used to create an excavator model, and the created model is linked with Mathworks’ Simulink so as to develop the co-simulation environment. Thus, the algorithm that remains robust to acceleration changes due to shocks was simulated.

**KINEMATIC ANALYSIS**

**Excavator Kinematics Analysis**

Generally, excavator stability is determined by its total CoM. The excavator can have support polygon and stabilize itself if its total CoM remains within its support polygon such as floor contact area. However, the excavator will lose the floor reaction and its CoM deviates from its support ploygon. This state is defined as the excavator’s unstable state. Excavator stability analysis concerns the discovery of its total CoM position.

In this paper, the excavator working system is assumed as a rigid body, and the excavator cabin’s swing motion is not considered. In order to express the excavator behavior on the Cartesian coordinate 5, the excavator coordinate system is set as in the Figure 1.

**Table 1. Excavator Model D-H Parameters**

<table>
<thead>
<tr>
<th>i</th>
<th>(a_{i-1})</th>
<th>(a_{i-1})</th>
<th>(d_i)</th>
<th>(\theta_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>(\theta_1)</td>
</tr>
<tr>
<td>2</td>
<td>(l_1)</td>
<td>0</td>
<td>0</td>
<td>(\theta_2)</td>
</tr>
<tr>
<td>3</td>
<td>(l_2)</td>
<td>0</td>
<td>0</td>
<td>(\theta_3)</td>
</tr>
<tr>
<td>4</td>
<td>(l_3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In the above D-H Parameters, the motion of the working system its location and posture, which consists of the boom, arm and bucket, is expressed in terms of each displacement function of working systems as in (1).

\[
\begin{pmatrix}
\theta_{212} & -\theta_{233} & 0 & L_xc_1 + L_xc_1 + L_xc_1 \\
\theta_{233} & \theta_{233} & 0 & L_xc_1 + L_xc_1 + L_xc_1 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{pmatrix}
\]

The bucket end-effect’s locations, namely, \(p_x, p_y, \phi\) are created as in (2).

\[
P_x = l_xc_1 + l_xc_1 + l_xc_1 \\
P_y = l_xc_1 + l_xc_1 + l_xc_1 \\
\phi = \theta_1 + \theta_2 + \theta_3
\]

If the final excavator joint angles, namely, \(\theta_1, \theta_2, \theta_3\) are given, each axis’ arbitrary location can be evaluated, using the above expression.

**Cylinder Kinematics Analysis**

Using the kinematic analysis, the relational expression was determined between the excavator’s joint coordinate and Cartesian coordinate. However, the hydraulic excavator behavior is driven by the hydraulics cylinders attached to the boom, arm and bucket. Thus, in order to know the joint angle, the relational expression between the joint and cylinder is needed. Figure 2 show the coordinate system and parameters defined to evaluate the relational expression between the boom and the hydraulic cylinder.

\[
l_{bxy}^2 = l_{b1}^2 + l_{b2}^2 - 2l_{b1}l_{b2} \cos \alpha_b
\]
Thus, the angle $a_5$ created by the cylinder can be defined as in (4).

$$\cos a_5 = \frac{l_{s1}^2 + l_{s2}^2 - l_{bcyl}^2}{2l_{s1}l_{s2}}$$

$$a_5 = \cos^{-1} \left( \frac{l_{s1}^2 + l_{s2}^2 - l_{bcyl}^2}{2l_{s1}l_{s2}} \right)$$  \hspace{1cm} (4)$$

Finally, using the relationship between the boom and the hydraulic cylinder, the following relational expression (5) between the hydraulic cylinder displacement and joint angle can be evaluated.

$$\pi = \theta_1 - \delta_{b2} + a_5 + \delta_{s1}$$

$$\therefore \theta_1 = \pi + \delta_{b2} - a_5 - \delta_{s1}$$  \hspace{1cm} (5)$$

Figure 3 shows the coordinate system and parameters defined to evaluate the relational expression between the arm and the hydraulic cylinder.

Fig.3. Arm Cylinder Coordinate and Parameters

The arm has a similar structure to the boom, so in the same method as with the boom, its rotational relationship between the hydraulic cylinder and the joint angle can be evaluated. The result is as per the following.

$$l_{arm}^2 = l_{s1}^2 + l_{s2}^2 - 2l_{s1}l_{s2} \cos a_s$$

$$\cos a_s = \frac{l_{s1}^2 + l_{s2}^2 - l_{arm}^2}{2l_{s1}l_{s2}}$$

$$a_s = \cos^{-1} \left( \frac{l_{s1}^2 + l_{s2}^2 - l_{arm}^2}{2l_{s1}l_{s2}} \right)$$

$$\pi = \delta_{s1} + a_s + \delta_{s2} - \theta_2$$

$$\therefore \theta_2 = \pi + a_s + \delta_{s2} - \pi$$  \hspace{1cm} (6)$$

Figure 4 shows the coordinate system and parameters defined to evaluate the relational expression between the bucket and the hydraulic cylinder. The bucket has a four link structure, so it needs a different method from the previous one.

Fig.4. Bucket Cylinder Coordinate and Parameters

First, the hydraulic cylinder and the four-bar linkage start area can be evaluated with the same method as the boom. The result is shown as in (7).

$$l_{bcyl}^2 = l_{s1}^2 + l_{s2}^2 - 2l_{s1}l_{s2} \cos a_{s1}$$

$$\cos a_{s1} = \frac{l_{s1}^2 + l_{s2}^2 - l_{bcyl}^2}{2l_{s1}l_{s2}}$$

$$a_{s1} = \cos^{-1} \left( \frac{l_{s1}^2 + l_{s2}^2 - l_{bcyl}^2}{2l_{s1}l_{s2}} \right)$$  \hspace{1cm} (7)$$

Using the kinematic constraint conditions, the rotational value $a_{s3}$, which changes according to the hydraulic cylinder, can be defined as in (8).

$$2\pi = a_{s2} + \alpha_{s1} + \beta_{s2}$$

$$a_{s2} = 2\pi - a_{s1} - \beta_{s2}$$  \hspace{1cm} (8)$$

The four-bar linkage can be defined as follows using the second cosine law, and thus all rotations within the four-bar linkage can be defined as in (9).

$$l_{link} = \sqrt{l_{s2}^2 + l_{s5}^2 - 2l_{s2}l_{s5} \cos a_{s2}}$$

$$a_{s3} = \cos^{-1} \left( \frac{l_{link}^2 + l_{s5}^2 - l_{s2}^2}{2l_{link}l_{s5}} \right)$$

$$a_{s4} = \cos^{-1} \left( \frac{l_{link}^2 + l_{s4}^2 - l_{s2}^2}{2l_{link}l_{s4}} \right)$$  \hspace{1cm} (9)$$

Using the kinematic constraint relationships, the bucket rotation that we want to know finally was determined as in (10).
Finally, the joint velocity and acceleration relationship between cylinder and joint angle is calculated by differential method.

\[
\dot{\theta} = \frac{d\theta}{dt}, \quad \ddot{\theta} = \frac{d\dot{\theta}}{dt} \quad (11)
\]

**Kinetic Analysis**

In order to apply ZMP for preventing excavator tips-over, firstly, we need to know CoM (Center of Mass) point acceleration each link because force and moment is a function of acceleration. Thus, the each joints expression, determined above, should be differentiated into velocity and acceleration expression for CoM point each link.

In order to map the relationship between joint coordinate and Cartesian coordinate, Jacobian should be used.

First, using the kinematic analysis, the position function \( X_F(q) \) should be evaluated, and the corresponding result is partially differentiated as much as the joint variable to obtain Jacobian \( J_q \). If the result is partially differentiated again, the acceleration Jacobian \( J_{\ddot{q}} \) can be obtained. This can be expressed in terms of expression as in (12).

\[
X = F(q) \\
\dot{X} = \frac{dF(q)}{dq} \frac{dq}{dt} = J_\dot{q} \\
\ddot{X} = J_{\ddot{q}} + J_\dot{q} \quad (12)
\]

Using the above Jacobian analysis, the relationship between joint coordinate and Cartesian coordinate was determined.

**STATIC COMPENSATION ZMP**

**CoG (Center of Gravity)**

Generally, the excavator CoG can be calculated if all moving links are separated, and if the position and weight of separated links are known.

If the CoM (Center of Mass) position and its total weight of each link is known, CoG can be calculated on the Cartesian coordinate using the following expression.

\[
X = \sum \frac{W_i \times X_i}{\sum W_i}, \quad Y = \sum \frac{W_i \times Y_i}{\sum W_i}, \quad Z = \sum \frac{W_i \times Z_i}{\sum W_i} \quad (13)
\]

Each link’s weight is multiplied, and the result is divided by the total weight. Then, we know the CoG entire excavator. However, this method does not consider moment effect.

**ZMP (Zero Moment Point)**

The general ZMP (Zero Moment Point) algorithm was used to assess the walking stability of biped walking robots. ZMP is a point on the floor where the resultant moment of the gravity, the inertial force of the system and the external force is zero\(^6\). The excavator coordinate system about the inertial coordinate system is defined as in Figure 5.

\[
\text{Fig.5. The Excavator Coordinate System and The Inertial Coordinate System.}
\]

The mapping between inertial coordinate and excavator coordinate is as in (14)

\[
\begin{align*}
(X_{ZMP}, Y_{ZMP}, 1)^T &= R \times (X_{ZMP}, Y_{ZMP}, 1)^T \\
\end{align*}
\quad (14)
\]

Figure 6 shows the relationship with the arbitrary mass system in the system coordinate system.

\[
\text{Fig.6. Definition of vectors for system}
\]

The following equation of motion at an arbitrary point on the ground P is defined, which is acquired by applying d’Alembert principle.
The position vector of the mass center to the point P is described as in (16). If the point P is ZMP, the position vector is $\mathbf{p}_{\text{ZMP}} = [x_{\text{ZMP}}, y_{\text{ZMP}}, 0]^T$ and the total moment is $\mathbf{M}_p = [0, 0, M_p]^T$.

$$\rho = \frac{1}{m} \sum m_i (r_i - p)$$ (16)

Generally, Tele-operation excavator applied does not have a sensor system to measure external force because external force is very high power than biped walking robot and there is no force sensor to measure high power. If external force does not exist, can be determined as in (17), (18) in terms of $x$, $y$ ZMP component.

$$x_{\text{ZMP}} = \sum m_i (\ddot{z}_i + g) s_i - \sum m_i \ddot{z}_i s_i$$ (17)

$$y_{\text{ZMP}} = \sum m_i (\ddot{z}_i + g) t_i - \sum m_i \ddot{z}_i t_i$$ (18)

The above equation, applied to the tele-operation excavator, is applied to get the position of CoG preventing excavator tips-over. Where, $m_i$ = each component’s mass, $s_i$, $t_i$, $z_i$ = position coordinates value of the each component, $g$ = acceleration of gravity.

**Static Compensation ZMP**

Excavators, which use high-power hydraulic cylinders, generate great shocks in the driving unit according to changing behaviors. The shock created in the driving unit can be seen as force, which means a sudden acceleration change. Thus, the ZMP algorithm, which uses the acceleration, sensitively responds to acceleration changes.

In order to address these problems, we propose a method to analyze the correlation between the excavator CoG and ZMP to reduce ZMP errors.

Figure 7 shows ZMP and CoG positions that can be obtained when the sinusoid is applied to each cylinder of the excavator according to time. If the difference between ZMP and CoG is evaluated from the above calculation, $F_{\text{diff}}(t)$ can be evaluated. Generally, due to inertial influence, ZMP value has always greater value toward the increasing movement direction than CoG value. And, the acceleration function ZMP and the position sum CoG creates great difference due to inertia, so, if the relevant system's instantaneous acceleration is determined, the maximum error scope can be defined.

By this concept, if the difference $F_{\text{diff}}(t)$ between $F_{\text{CoG}}(t)$ and $F_{\text{ZMP}}(t)$ deviates from the maximum error scope, this can be limited by cylinder maximum acceleration specification. Frequency analysis, which is low-pass-filter, apply to the $F_{\text{diff}}(t)$ function to minimize high frequency noise more than control signal. After signal processing $F_{\text{diff}}(t)$ add to $F_{\text{CoG}}(t)$. Finally, the overall ZMP error can be reduced by static compensation ZMP. Figure 8 shows the SCZMP(Static Compensation ZMP) algorithm flow chart.

**SIMULATION**

**Co-Simulation System**

The excavator model for simulation was created by RecutDyn Dynamic Simulator, and these parameters used for simulation model shows Table 2.
Fig. 9. RecurDyn & Matlab Simulink Co-Simulation Block Diagram for Excavator Dynamic Simulation

Table 2. Excavator Model Parameters for Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{sp}$</td>
<td>200 mm</td>
<td>$L_1$</td>
<td>368.40 mm</td>
</tr>
<tr>
<td>$x_1$</td>
<td>22.5 mm</td>
<td>$L_2$</td>
<td>136.59 mm</td>
</tr>
<tr>
<td>$x_2$</td>
<td>110 mm</td>
<td>$L_3$</td>
<td>115.78 mm</td>
</tr>
<tr>
<td>$x_3$</td>
<td>21 mm</td>
<td>$l_1$</td>
<td>160.20 mm</td>
</tr>
<tr>
<td>$dx$</td>
<td>21 mm</td>
<td>$l_2$</td>
<td>50.80 mm</td>
</tr>
<tr>
<td>$m_{drivem}$</td>
<td>9.11 kg</td>
<td>$l_3$</td>
<td>60.49 mm</td>
</tr>
<tr>
<td>$m_{cabinm}$</td>
<td>16.94 kg</td>
<td>$\mu_{\text{max}}$</td>
<td>51.74 mm</td>
</tr>
<tr>
<td>$m_{boomm}$</td>
<td>7.07 kg</td>
<td>$\alpha_1$</td>
<td>14.70 deg</td>
</tr>
<tr>
<td>$m_{armm}$</td>
<td>1.69 kg</td>
<td>$\alpha_2$</td>
<td>10.79 deg</td>
</tr>
<tr>
<td>$m_{bucket}$</td>
<td>0.19 kg</td>
<td>$\alpha_3$</td>
<td>23.84 deg</td>
</tr>
</tbody>
</table>

The shock created in the driving unit, which means a sudden acceleration change, was modeled by Gaussian Distribution Noise in Matlab Simulink function block. This shock can be seen as force, which means a sudden acceleration change. The ZMP algorithm, which uses the acceleration, sensitively responds to acceleration changes.

Static compensation ZMP algorithm was developed by Matlab Simulink in Figure 9 which is very convenient method to simulate dynamic algorithm. Finally, we simulate CoG, ZMP, and Static Compensation ZMP algorithm using Co-Simulation(RecurDyn & Matlab Simulink) method.

Simulation Configuration
Simulation input is sinusoidal signal as each cylinder velocity during 3 seconds. Table 3 shows boom, arm, and bucket cylinder velocity input parameters.

Figure 10. Shows sequence of simulation process. Red circle is path of CoM(Center of Mass) respectively. (a) is displacement graph of boom, arm, and bucket cylinder. (b) is velocity graph of boom, arm, and bucket cylinder. (c) is acceleration graph of boom, arm, and bucket cylinder.

The model is carried out cylinder displacement from the input. This is converted by cylinder kinematics to each joint angle. Also, joint angular velocity and acceleration are derived from differential equation of joint angle. And then, we get the velocity and acceleration of each link CoM point on Cartesian coordinate system. Finally, we get the CoG, ZMP, and Static Compensation ZMP result.
Simulation Result
Figure 11 is simulated by adding noise, which has Gaussian Distribution, to each joint acceleration.

Fig.11. Stable Result with cylinder acceleration noise

From the above result, we can see that ZMP value have much noise more than SCZMP value.
To simulate excavator stability when its CoM is in the support polygon. We change simulation input parameters. Table. 4 shows simulation input parameters.

Table 4. Excavator Cylinder Input Parameters for Unstable Simulation

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>0 ~ 3 second</td>
</tr>
<tr>
<td>Boom Cylinder Velocity</td>
<td>-160 ~ 160 mm/s</td>
</tr>
<tr>
<td>Arm Cylinder Velocity</td>
<td>-125 ~ 125 mm/s</td>
</tr>
<tr>
<td>Bucket Cylinder Velocity</td>
<td>-30 ~ 30 mm/s</td>
</tr>
</tbody>
</table>

Figure 12 shows CoM value is out of support polygon area. Figure 13 shows excavator stable, and unstable result, respectively.

Fig.12. Unstable Result with cylinder acceleration noise

Figure 13 (a) is stable excavator motion, (b) is unstable excavator motion.

CONCLUSION
In this paper we introduced Static Compensation ZMP algorithm. This algorithm can be conformed that a more accurate output, compare with general ZMP algorithm. Also we show excavator tips-over when its total CoM out of its support polygon such as floor contact area.

ACKNOWLEDGMENT
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