Proceedings of the 20th International Symposium on Automation and Robotics in Construction

ISARCC2003 The Future Site

Editors:
Ger Maas
Frans van Gassel

Technische Universiteit Eindhoven
The Netherlands
This publication is the Proceedings of the 20th International Symposium on Automation and Robotics in Construction (ISARC). The symposium was held at the Technische Universiteit in Eindhoven, The Netherlands during 21-24 September 2003. The Proceedings include the technical program, list of Review Committee, Message from the Organisers and the 99 technical papers from 23 countries authored for this international meeting.

The manuscripts were presented during 22 Sessions.

KEYWORDS

Automation, Construction, Construction Equipment, Construction process integration. 4D construction simulation, Industrial construction, Robotics. Simulation

COLOFON

Editors : Ger Maas and Frans van Gassel
Bouwsteen : 74
Coverdesign : Ton van Gennip, Design Studio Technische Universiteit Eindhoven
Lay out : Philomeen Wessels, www.uwofficemanagement.nl, Jeroen Harink, Marcel Hartjes
Printing : PrintPartners Ipskamp, Enschede

Technische Universiteit Eindhoven
Construction Engineering and Management
Department of Architecture, Building and Planning
P.O.Box 513
5600 MB Eindhoven
The Netherlands

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG
Editors : Ger Maas and Frans van Gassel

Proceedings of the 20th International Symposium on Automation and Robotics in Construction
ISARC2003 The Future Site
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ISBN 90-6814-574-6
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WELCOME TO THE FUTURE SITE

A nice spot:
Where you can linger, where things are treated with care, where the earth does not have to suffer irreparable damage, where some things are left whole for future generations, where partners join forces to make things better for one another, where people have time to take on new technical challenges, where users are pleased when they come into their new homes without having to take a sheet of paper to write down all the completion defects, where customers are equal partners and have a say in the design of their new homes, where workers are not worried about their health and the wear and tear on their bodies, where people can reach retirement age without handicaps, where constructability is part of the design.

A Future Site made possible by Industrial, Flexible and Demountable construction. IFD: more a way of thinking than a method. A way of thinking in which the design of the project runs along two different lines. The first line is the design of the structure as a product and embodiment of the user’s wishes. The second line concerns the design of the structure seen from the perspective of the production process. The integration of these two lines creates new innovative possibilities.

What kind of new and innovative technologies will we be using in the future to ensure rapid and inexpensive building, while maintaining proper levels of quality of the construction site?

ISARC2003 The 20th edition of the IAARC-sponsored symposia on automation and robotics in the construction industry is the latest in a successful series of ISARC annual symposia held since 1984 at various locations in the United States, Europe, Japan and Taiwan. ISARC2003 will offer participants the opportunity to attend more than 99 interesting keynote and technical presentations by individuals from more than 23 countries. Several outstanding international speakers will address the conference in plenary sessions. In 22 specialised tracks the developers and researchers may exchange and discuss the latest ideas. In addition, a technical program was included in this symposium.

The international Advisory Board and the Organising Committee have received strong support from various organisations related to Automation and Robotics in Construction, namely IAARC, CIB and IEEE. Several Dutch and Belgian Institutions were actively involved in creating a promising program for this event, namely TNO, BBRI and SEV.

Finally, we would like to thank everyone whose support, commitment, enthusiasm, contribution and encouragement has made this symposium possible.

We hope that new insights, ideas, contacts and plans will contribute to a successful symposium and bring us a step closer to a better ‘Future Site’.

The ISARC2003 Organising Committee
ACKNOWLEDGEMENTS

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Keynote Papers and Presentations
The Future Site,
Report on a Quest for the Drivers of Change

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ABSTRACT: When speaking about The Future Site we presume that in future a site will be different from the present building site. We take it for granted that almost every thing in our modern world is subject to permanent change. But to develop a vision on how that future site will look like it is necessary to develop first a vision on how our world will change in the near future. Changes on building sites are like many things a consequence of a changing world. To state it more specifically: the changes on the building sites will be driven by changes in our culture, our life style, and prosperity, and also - but not exclusively - by developments in knowledge and technology.

The most important drivers for change identified in this paper are the changing values of society. Both legislative and regulatory authorities as well as the end-users of the products of the construction industry are forcing the industry to another way of producing and delivering buildings. As a result the construction process has to be industrialised to an extent not yet feasible. In the course of this process of industrialisation new entrants with a core-business in other industries may appear on our market. Outsiders not programmed by the existing building culture and therefore better qualified to understand and adapt to new rules.

KEYWORDS: Building Site, Drivers for Change, Industrialisation, Mass Customisation, Trends.

1. INTRODUCTION

The Isarc conference 2003 has chosen The Future Site as its leading theme. Many delegates will present us their views on this subject. We all are confident that the future building site will be different from the present standard. None of the submitted papers doubts whether there will be a change or not. As an introduction to the subject I would like to pose the question “Why will that future site be different?”

The answer is not exclusively found in the availability of new knowledge and new technologies. It can also be found in a changing environment. In this paper 6 aspects of a changing world are identified. That means 6 different reasons why the construction industry will have to change its building processes and products. The list below may be far from complete. I expect that we will agree after listening to all presentations in this conference that there are even more then 6 drivers for change. Possibly we will be able to rank them from most important to of minor influence. Or should we rank them from most threatening for the continuity of our business to less dangerous. Or to say it in a more positive way: From most challenging for the building research community to less demanding. The provisional list I identified reads as follows:

1. Changing values
2. Changing attitude towards technology
3. Clients’ growing awareness
4. Globalisation
5. Industrialisation
6. New Entrants

2. CHANGING VALUES

Our society is changing because of an increasing level of prosperity. This enables us to enjoy a better quality of live than our parents did. It also enables us to maintain that quality of life for a
much longer period. We grow much older than previous generations. Above that we have more income to spend. This increasing quality of life causes our governments to set higher standards for peoples’ welfare. The risk of being subject to a fatal accident is less acceptable than it was ever before. Construction is – together with transportation – among the most risk full activities of our modern society. Both ask for a heavy toll of human live every year in every country. Construction is also – and again jointly with transportation – an activity most hindering for neighbouring people. And on top of that construction is exhausting resources and polluting the environment. So we cannot deny that construction is a threat to the quality of live. Therefore governments all over the world develop policies to reduce this toll of live, this hinder and pollution.

For the future building site this policy will have consequences:
• The building site has to be safer,
• Causing less hindrance,
• Producing less waste,
• Work must be less damaging for the health of labourers.

3. CHANGING ATTITUDE TOWARDS TECHNOLOGY

Not only is the acceptance of our processes decreasing. The whole sphere of work of engineers is loosing appreciation. Technical professionals are easily associated with air pollution, radiation and noise. On top of that technical studies are supposed to be difficult. Such studies are considered to be only suitable for nerds and wiz kids. The new generation prefers studies like business administration and aims for glossy jobs with “manager” or “consultant” on their business card. Many technical faculties are faced with a decreasing number of students. As a consequence of this construction companies find it more and more difficult to fill their ranks with young professionals to replace the greying baby boomers.

If we want to change this tendency we should know what the reason is for this negative perception. Why can our companies not attract sufficient well educated and motivated youngsters like it did before? I see 6 mayor drivers:
• The society doesn’t accept our traditional process any more.
• Students do not want to become part of an old fashioned system,
• Construction is supposed to be low tech,
• Construction is supposed to provide a low quality
• Construction is not client friendly,
• Construction companies are mistrusted.

Where I write “is supposed” it is suggested that the others may be wrong. We could better take the view that a client is always right. We should look for the reasons internally. The construction industry has to meet the higher expectation in respect of technology, quality, client focus and reliability.

4. CLIENTS GROWING AWARENESS

The focus on clients has never been a characteristic of the building industry. In many countries housing is in short supply. Land for new construction projects on attractive locations is also in most communities a rather precious good. So project developers and construction companies are in most cases in a strong position. Until recently construction was operating on a sellers market. But clients are nowadays more aware of there position and power than ever before. Pleased by the customised mass production of the automotive industry, the computer industry and many other suppliers of consumer goods our clients expect also from the construction industry a more or less tailor made product. An attitude hard to handle for the construction industry as a whole. But there are examples of mass customisation. [Tomonari] In the Japanese housing industry it is possible to order a prefabricated house to clients’ specifications. Of course provided that these specifications remain within the limits determined by the production lines and the transportation over public roads. In Rotterdam, The Netherlands, recently a housing project was developed where all future tenants were offered the opportunity to have there own facade designed and build. [Figure 1] [Beemster] [Scheublin 2002]
The prospective buyers selected an architect from a shortlist prepared by the project development company and specified their personal preferences and ideas. As a result a facade with a great variety in materials and styles came out. Cost consequences forced the visionary developer to reduce the freedom of choice. But a new approach was born. Clients were pleased by the given opportunity. This may be a first milestone on the road to a more client focussed approach. The traditional building industry will have to adapt to such a new attitude. Otherwise they may loose an important part of their market to the builders of semi-permanent facilities.

5. GLOBALISATION

The world got virtually much smaller over the last decades. And it is still shrinking very quickly. Internet gave us the possibility to communicate with almost every person in the world, on line, without any substantial waiting time. Air transport became such cheap that almost everybody in the wealthy part of the world is able to travel where ever one wants to go. Trade barriers were dissolved. Even former communist countries entered into free trade agreements with Western powers. But construction is a rather local business. It does not react very quickly to new opportunities.

Nevertheless globalisation did already change the building industry. [Winch] Labour is now more frequently hired abroad. Densely populated countries in the Far East export labour to Middle Eastern countries with a lack of skilled construction labour. Middle and Southern Americans work in Northern America. Cheap labour from NAS-countries (Newly Associated States) will seek work all over the Europe when the EU opens its frontiers for labour from new member states. Design and engineering services are through internet supplied to engineering bureaus world wide by offices in low-wages countries. The labour market is already an international market and it will develop into a global market soon.

Does this development affect the industrialisation of the building site of the future? Yes, but not in a positive way. Cheap labour from low-income countries on building sites in high income countries may delay the move from production on-site to off-site prefabrication. Also automation of work on site may be less feasible when cheap labour comes available. But this factor will only disturb the labour market for a limited period of time. Its effect will be of a temporary nature. One day labour conditions will be harmonised. And though cheap on an hourly basis foreign labour is often less effective than automated systems and industrialised production.

A more lasting effect from globalisation will be the supply of labour intensive, high quality but low priced products, produced in low salary countries. Dissolved trade barriers and internet communication will enable this development. In particular easy transportable and complicated items like door locks, air conditioners and fixtures will be purchased on a global scale. The variety of countries of origin will increase. Competition will be intensified and prices of buildings may decrease by as much as approximately 10%. [BRE]

A research project by HBG, my employer, showed that free trade agreements did not immediately open borders. An effort to benefit from the international dimension of the company failed. Purchasing departments of HBG companies in Germany, the UK and The Netherlands compared prices of building materials and mechanical installations. It was obvious that substantial price reductions were possible through purchasing in neighbouring countries.

When this conclusion was tested in practice the results were disappointing. Dealers of international companies like producers of air conditioners and elevators appeared not to be allowed to sell to clients outside there territory.
Equipment from one country did not meet the national standards of another countries, though participants in the same free trade agreement. Suppliers did not accept installation work abroad. And finally language barriers were more difficult to overcome than expected. So though trade barriers are dissolved on paper. In practice there is still a long way to go. But it is foreseeable that in a not too far future purchasing for construction work will be an international activity on a global market.

6. INDUSTRIALISATION

Industrialisation is not at all a new phenomenon. It is a philosophy originating from the nineteenth century and was first applied in the USA and the UK. Its meaning grew with the development of steam machines, followed by combustion motors and electrical power. In recent decades it was the growing power of computers that contributed most to the ongoing process of industrialisation. In a definition of industrialisation we would use elements like machines replacing human power, planning and production of series. In this respect the construction industry can be seen as a late adapter. Of course the construction industry also benefited a lot from industrialisation. Human lifting of materials is almost fully replaced by tower cranes and other lifting equipment. A lot of other human work like mixing, sawing, boring etc is also replaced or supported by machines. Nevertheless, when compared with other industries, construction is lagging behind. There are still many man-years of manual work invested in each building process. Also planning is not as advanced as it is in most other industries. Frequent adjustments of the planning to the real progress on site are not unusual, to say it carefully.

But it is foreseeable that in the near future also the building process will be industrialised to a higher degree. The growing awareness among clients of an unacceptable quality, a sub-standard product and the higher standards for labour conditions and environmental care will force the industry to a better controlled process. A process with a mayor input from prefabrication plants. On site only assembly of big elements will take place. On future sites construction will be replaced by mounting of big elements. Hardly any labour will be left on site.

Some alternatives for manual work on site are:
- Prefabrication of voluminous elements,
- Prefabrication of panel / slab systems,
- Plug-and-play systems
- Click connection systems
- Robots on site.

7. NEW ENTRANTS

Contractors are facing a demanding and sometimes even hostile world. Clients claim that quality levels are below reasonable expectations. A zero defects product is considered to be the standard. Governments set higher standards for an environmental friendly process, a labour friendly process and a process without hindrance. Subcontractors try to sell their products and services direct to the end user. And the image of the building business is lower than ever before. Though it was never very high at all.

Under these circumstances clients are ready to look for alternative solutions. Solutions offered by other industries. Industries with a better reputation for quality and client focus. Such alternative builders who may enter the industry are:
- Shipbuilders
- Suppliers of temporary facilities
- Removable homes
- House boats
- Furniture suppliers
- Kitchen and sanitary industry
At the CIB sponsored conference on Re-valuing construction in Manchester [Scheublin 2003] A full analysis of the new entrants was presented. It was concluded that the construction industry is already loosing ground to new entrants. If the “old” industry does not change its processes than more and more new parties will enter and many may be successful.

One of the most extreme examples of a new approach was the Bolder Office Building [Figure 2]

That may be the direction the building side of the future is moving to.

A 10-storey office building, constructed on a shipyard, floated to its final destination and lifted on its foundation with a giant crane.

They all have another clients perception. Most of them do not tender for contracts

8. THE FUTURE OF IAARC?

In this quickly changing world there is no place for a conservative industry with a traditional process. The building process must be adjusted to meet the requirements of a modern society. In particular the building site, with its threat to health, safety and environment should be changed without delay. To achieve such a revolution in thinking and doing requires apart from a cultural change a lot of research. Of original thinking. Of alternatives.

IAARC-members are in the right position to support this movement. But IAARC and its members are not the only research partners for the construction industry. There are several other research communities, ranging from formal associations to informal networks. All these bodies bring together researchers from universities, from government agencies, from industry branch institutes, from big clients and many other innovative forces in the building industry. All these networks have their own conditions for membership and their own specific area of research.

There are even federations of networks, providing their membership with the services of a permanent secretariat. Funding for research from the European Union or the United Nations is often awarded through these federations for further distribution.

IAARC may consider to connect itself to one of these international networks and to benefit from the stronger position and the economy of scale.

Even when we come to the conclusion that IAARC does not need the benefits from a larger network it is still important to be aware of the growing competition for research budgets. We are not the only network. So we must demonstrate to be the better one.

This overwhelming participation in this ISARC 2003 conference is underlining IAARCS’ strength and its value to members. Lets keep in mind also our clients - the building industry - must benefit from our efforts. Their continued financial and moral support will give us the opportunity to keep contributing to a better future site.

9. CONCLUSIONS

It may be concluded that there are many drivers for change. Most drivers are basically the result of a changing society. A society with higher expectations in respect of quality of products, environmental care and care for good labour conditions.

As a result of these higher expectations the traditional industry must change its attitude and its processes. That means that the industry must industrialise. If traditional players are not able to meet the new requirements, companies with there roots in other industries will certainly conquer a part of the market that was traditionally reserved for the construction industry. Researchers may be
the first to be aware of this demand for change. It is our role to spread the message.

10. REFERENCES


This presentation presents the conventional and the smart lifting methods and systems used by the company Mammoet.

The following subjects will be presented:

1. Introduction Mammoet
2. Cranes
3. Containerised cranes
4. Alternative lifting methods
5. Other special devices
6. Lifting the Kursk
7. Future lifting methods

1. Introduction Mammoet

The core business of Mammoet is heavy lifting and transport services. Originating from Dutch roots and characterized by a professional networking culture, the enterprise has evolved to a world-class player that sets trends and records. In virtually every part of the world, the presence of Mammoet onshore and at sea is highly visible. Its regional offices serve customers in various markets around the globe. The main economic sectors Mammoet concentrates on are the petrochemical industry, civil projects, power plant facilities, offshore business and marine projects.

Mammoet relies on a vast and solid range of expertise to handle both standard and one-of-a-kind contracts alike: with dedication and passion of all concerned to ‘be the best full service provider in the global market for engineered heavy lifting and multi modal transport’. This ambitious mission statement materializes every day. A full range state of the art equipment and loyal professionals in its staff and crews are the main assets that ensure the successful completion of any activity. Mammoet accomplishes end-to-end services as main contractor, dedicated services as subcontractor, as well as rental services and a renowned tradition in trade.
Organization
Driven by the customers need to be within arm's reach, Mammoet applies a decentralized organization model. This results in regional establishments for the America’s, Europe / Africa, the Middle East and Asia. To enhance the commercial power, these offices can deploy activities fairly autonomously. All have a versatile range of equipment at their own disposal, including cranes, transport vehicles, jacking systems, ballasting systems and many more. Eased by thus simplified logistics, customers can be served quickly in compliance with the terms of contract. In several specific countries, Mammoet shortened the communications and service lines even further by enhancing local establishments. Many are run in joint ventures with reliable and proven partners that believe in mutual benefit and taking customer satisfaction as their focal point.

Apart from the four regional establishments, the organization model shows a fifth, yet essential, entry: Mammoet Global. Its main task is to direct and orchestrate major projects that involve operations in different regions. For reasons of efficiency and short cycle times, such projects need a central management. Mammoet Global also has its own fleet of equipment under direct control. Among these are the ten biggest cranes in the world. A key factor to the success in this high-end sector is the management of a flawless worldwide logistics that matches its pre-set planning at all times.

Special assets
The professionalism, skills and expertise of its employees are considered by Mammoet as its most precious asset. It is at the heart of all successful operations. A unique feature is that any Mammoet crew knows how to cope dynamically with unexpectedly changing circumstances. They show impressive flexibility, improvisation talents and a co operational attitude. In many projects, Mammoet participates on the spot in various teams with representatives of customers and other contractors. An open mind and communications make Mammoet known as a trustworthy partner that respects others interests.

Mammoet believes the pre-engineering of concepts and solutions for any project is the only way to keep control over lifting and transport jobs. Because most expenditures are already defined with the selection of the solution concept, Mammoet's goal is to have its Engineering department involved in an upcoming project as soon as possible. The optimization of the solution concept saves significantly time and cost to the benefit of the customer. In effect, the customers engineering experts that do the total design, can make full use of the lifting and transport limits, and thus may optimize their plans as well.

Finally, Mammoet maintains a highly respected Quality Safety Environment. It comprises standards that are in effect at any time and at any place for health aspects, safety of crews and investment goods, environmental issues and quality definitions for the technical performance. Subcontractors that work for Mammoet must comply with these standards, despite those local regulations and laws may require less strict rules.
In this chapter the different type of cranes will be discussed. Conventional cranes to the largest and most modern cranes.

- Mobile cranes
- Crawler cranes
- Tower cranes
- Ringer cranes
3. Containerised cranes

Mammoet unitised equipment by containerising. Containerisation of equipment is done in three ways:

- Containerised: equipment is dimensioned to fit into a container
- Container: equipment is a container (powerpack)
- Container-sized: equipment is dimensioned to become a container with help of support frames

This led to cheaper and faster transport than conventional transport. The turnaround times and transport costs from Rotterdam to Houston of two ringed cranes, with each a lifting capacity of 2000 tonnes, are compared in table 1 and 2. The containerised PTC is transported by

![Figure 1: Container-sized boogy and ring part of the PTC](image)

containership. A general cargo ship with loading cranes transports the Platform Ring.

<table>
<thead>
<tr>
<th></th>
<th>Platform Ring</th>
<th>PTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid and Transport</td>
<td>10 weeks</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Assembly</td>
<td>10 days</td>
<td>16 days</td>
</tr>
<tr>
<td>Lift</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Dismantling</td>
<td>10 days</td>
<td>16 days</td>
</tr>
<tr>
<td>Transport</td>
<td>10 weeks</td>
<td>3 weeks</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>± 6 months</td>
<td>± 3 months</td>
</tr>
</tbody>
</table>

|                              | Platform Ring | PTC           | Container |
|------------------------------|---------------|---------------|
| Loading Rotterdam            | €22,785       | €15,980       | 94*€170 All |
| Transport (shipping)         | €603,802      | €45,150       | 43*€1,050 20 ft. |
| Off Loading Houston          | €56,963       | €49,260       | 94*€524 All |
| **Total Costs**              | €683,550      | €177,200      |

The PTC and MSG are the first containerised cranes. Container-transport is an economical and fast method to transport general cargo since containers are an International Standard.
**Pro’s**

- Containerships sail faster, on- and offloading-time is shorter, the reasonable constant shipping costs are lower and departure more frequent.
- Container is an International Standard. Standard handling equipment for intermodal transport and transshipment of containers is used worldwide.
- Easy storage, little space required because of ability to stack.
- Composing equipment of containerised parts does not only have a transport advantage: all containerised parts are relatively small and light, assembly can be done by a smaller support cranes.
- The container-shipowners are trustworthy and co-operative.
- For the modular parts of the crane a 40 ft. container size is considered preferable to fabricate and joint-construct but a 20 ft. container size is more economical (mass/volume) and easier to transport in countries with an underdeveloped infrastructure.

**Con’s**

- Assembly time on site will be longer.
- All cargo must be sized within container dimensions and masses or the transport advantage will be lost. The design and construction costs will be higher.
- Container dimensions limit stiffness and strength of equipment parts.
- Pre and post transport will always be necessary, which can result in higher total transport costs.
4. Alternative lifting methods

The Mammoet Advanced Strand Lift System

Mammoet has designed the Mammoet Strand Lift System to be used in the MSG -Mammoet Sliding Gantry- Systems as well as for installation of heavy equipment, such as offshore-structures, equipment for petrochemical and nuclear power plants, bridges etc.

The system has a modular set-up, designed for safe and precise lifting, lowering or pulling of heavy loads.

The growing capacity, which Mammoet has available, already exceeds 24,000 mTonnes, based on the following two types:

- LI-010 with 600 mTonnes lifting capacity/unit
- LI-011 with 900 mTonnes lifting capacity/unit

_Lifting 6.700 mTonnes deck with 12 strand jacks_
Both are very compact, liable and economic solutions for every lift. Due to its compact design, it is very suitable in areas where conventional equipment cannot be placed. Since all lifting operations are remotely controlled and monitored, people can stay in a safe area on the ground.

The system is composed out of the following main items:

1. The strand lifting unit SSL
2. The manifold box
3. The control computer
4. The compact strand bundle
5. The hydraulic power pack
1. The Strand Lifting Unit SSL

The strand lifting unit components:
- Base plate
- Lower anchor head with wedges
- Hydraulic cylinder
- Upper anchor head with wedges
- Stroke transducer
- Pressure transducer
- Wedge-release-cylinder
- Safety valve

**Operation:**
18 mm compact strands are installed through the unit and locked in the lower anchor head.
The upper anchor head closes and grips the strands, the piston of the jack extends and raises the closed upper anchor head including the strands.
In top position, the piston lowers to the starting position after releasing the strands with the load to the closed lower anchor head and opening the upper anchor head.

In case of lowering, the procedure will be reverse, the upper anchor head will be closed and hold the load, while the bottom anchor head will be opened.
Closing and opening of the anchor heads is done by the lower and upper wedge release cylinders.
Safety valves are integrated into the strand lifting unit in order to stop the cylinder movement in case of hose break.
During the whole cycle, the stroke, the hydraulic pressure and the position of the wedges is monitored constantly by computer and indicators mounted throughout the system.
2. The Manifold Box

The manifold box is the interface between the strand lift unit, the hydraulic powerpack and the control computer. The communication card receives information from the strand lift unit, sends it to the control computer and receives commands by the control computer to operate the hydraulic valves to direct the oil flow.

3. The Control Computer

The control computer is a standard computer, equipped with the smart cylinder control-system (SCC). SCC is specially developed to control hydraulic lifting equipment. The main characteristic is, that every cylinder has got its own controlling print which is connected by a serial connection to the central computer. The computer is able to instruct and receive information for each controlling-print. As a result, the control over the hydraulic valves and the reading of the sensors is locally organised by a controlling-print, while a total picture is built in the central computer. Consequently, the central computer is able to co-ordinate the movements of all connected cylinders at once, while connections between the computer and the separate cylinders contain only one communication-cable.

The SCC controlling-prints are built into the manifolds and are provided with an individual electrical source, through which the valves and sensors are fed as well. The 220V supply for the manifold is send through the central computer box. As soon as the emergency stop is handled, the 220V supply ceases to operate, resulting in a situation in which all controlling-prints are without electricity and all movements will be stopped.

The system is stroke-controlled which means it makes sure all cylinders, despite any difference in oil flow and load, keep the same stroke when loaded. Besides the stroke, the load in each cylinder will be watched during operation. Movements will be stopped immediately by the computer when a higher load as expected occurs during the lifting or lowering sequence, this in order to prevent any overload of lifting points, structures etc.

16 Lifting Units in total can be controlled at the same time by one computer and several computers can be linked together to control even more lifting units. The whole lift can be recorded on computer disk so after completion of the lift, the history is available for investigation purposes if required.

For each individual cylinder the following information is shown on the console:
Console layout

Lifting with 12 jacks simultaneously, fully controlled by "the click of the mouse"

Stroke in mm  ; absolute position of the cylinder.
Load in kN  ; actual load on the piston.
Lift in mm  ; movement of the loaded piston.
Total lift in mm  ; sum of all movements.
4. The Compact Strand Bundle

The strand bundle is build up out of 36 or 54 single strand wires which contains 7 twisted, high capacity, steel strings. They are specially developed for heavy lifting and its length can be upto 1500 meters to meet the job requirements. At the end of the strand bundle an anchor point is connected with fixed wedges. This anchor point can be connected to the load.

5. The Hydraulic Power Pack

For the hydraulic power packs different systems can be used together, diesel or electrically powered. They deliver a high flow for the main cylinder movement and a constant pressure for movement of the wedge release cylinders.

6. Safety and Reliability

Due to its unique mechanical gripping action the strand lift system is a fail safe and “fool proof” system. One can never open two anchor heads at the same time once a load is picked up. Besides this mechanical safety, the computer will always warn the operator if something unexpected is happening. If, for example, the load exceeds the pre-set weight, it will stop the operation and makes the operator to check out and solve the problem before continuation. The movement of the load can be stopped at any desired position and without displacement. The load can be mechanically fixed through the lifting structure.

7. Technical Data

<table>
<thead>
<tr>
<th></th>
<th>Strand Lifting Unit Type LI-010</th>
<th>Strand Lifting Unit Type LI-011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit capacity (kN)</td>
<td>6000</td>
<td>9000</td>
</tr>
<tr>
<td>Total height/length (mm)</td>
<td>1780</td>
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<tr>
<td>Total weight (kg)</td>
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<td>Safety factor</td>
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<td>2.5</td>
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<tr>
<td>Certification</td>
<td>Lloyds</td>
<td>Lloyds</td>
</tr>
<tr>
<td>Type of cable</td>
<td>Dyform Strand</td>
<td>Dyform Strand</td>
</tr>
<tr>
<td>Number of strands</td>
<td>36</td>
<td>54</td>
</tr>
<tr>
<td>Nominal diameter of strand (mm)</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td><strong>Type of jack</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWL (kN)</td>
<td>6000</td>
<td>9000</td>
</tr>
<tr>
<td>Working oil pressure (bar)</td>
<td>370</td>
<td>400</td>
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<td>Test capacity (kN)</td>
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<tr>
<td>Test oil pressure (bar)</td>
<td>440</td>
<td>470</td>
</tr>
<tr>
<td>Stroke</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>
Nuclear. Exchanging reactors
Special lifting frames are designed for these purposes.
Building new windmills offshore.

Offshore windmill erection by means of a jack-up barge with a M1200 crane installed.
5. Other special devices.

*2400 tons jacking system*

The Jack-up System was developed by Mammoet, for the jacking of ultra heavy structures and modules. The system has a modular set-up, with a capacity of 2,400 mTonnes per set, including own weight.

During the jack-up there are two modes, Jack-Mode and Pack-Mode:

**- Jack-mode:**
Initial situation:
The 4 Locking Pins are inserted into the holes of the Jack Column.

The jacks in the skidshoes will be extended by hydraulic pressure. By extending these jacks, the Jack Column will be raised. The load on top of the Jack Column will be distributed from the Jack Column, by the jack, to the 4 hydraulic interconnected jacks. Jacking will be done in steps of 500 mm per stroke. After each stroke the Insert or a new Typical Jack Column will be inserted. Bolt connection will be made between the new inserted Typical Jack Column and the jackcolumn.

**- Pack-mode:**
By retracting the jacks the Jack Column will be lowered onto the Jack Column Support. All load will go directly from this support to the foundation. Retract the locking pins out of the jack column. The Jack-Frame will be lowered by retracting the jacks in the skidshoes. Insert the Locking Pins in lower holes of Jack Column. System is ready for the next Jack-Mode.

This sequence will be repeated until the required elevation is reached.

**Tailing frames**

Instead of tailing cranes, for upending vessels, special tailing frames are designed.
6. Lifting the Kursk

Introduction.

Between May 18 and October 23 2001, the eyes of the world focused on an extraordinary project carried out by two Dutch companies, Mammoet and Smit International: The Raising of the Kursk. This nuclear submarine, which sank following an explosion in August 2000, lay in 108 meters of water at the bottom of the Barents Sea with the bodies of more than 100 men and a substantial part of its weaponry still onboard. The location and adverse weather made this an exceptionally complicated project. Numerous innovations were needed to overcome the many problems. Raising the Kursk became a story of technological ingenuity, perseverance and courage in a fight against time and the elements. Many lessons were learned from the project and no doubt many more still can be learned from it. This video is a document of the successful operation, and also a virtual monument to the specialists from many countries that helped raise the Kursk and not least to the Kursk itself and its crew.

Lifting method.

The salvage plan generally looks as follows:

The Kursk, 115 meters long, lies at a depth of 108 meters below sea level, 70 miles of Murmansk. Its heavily damaged nose sunk into the seabed clay. To yield a compact object that can be handled during the lifting operation, the damaged front section will be cut off by a special designed robotic cuttingwire.

The salvage plan involves lifting the Kursk by means of 26 computer-controlled lifting units, all positioned on a barge. Once the barge is in place, 26 grippers – lifting hooks – will be guided down into 26 pre-cut holes in the inner and outer hull. When correctly aligned, the gripper units will be hydraulically opened up and clamped under the frames of the inner hull, not unlike a toggle bolt. A bundle of 54 cables will be attached to each gripper.

The cables are lifted by means of strand jacks that are situated on the deck of the barge. Each strand jack has a lifting capacity of 900 tonnes. Strand jacks lift hydraulically with a special gripping motion, not unlike climbing a rope, hand over hand. They are often used for heavy lifts, but usually on land.

During the lift, the force exerted on the attachment points on the Kursk needs to be constant. To maintain stability, the strand jacks will be fitted on top of a series of heave compensators that act like shock absorbers. They will allow the barge to move up and down while controlling the required tension on the strands. The lifting will be precisely controlled, centimeter by centimeter. The force on each bundle of cables can be set individually to minimize the tension on the hull of the Kursk.

In the presentation the lifting system will be explained in further detail.
7. Future lifting methods

The following lifting devices will be shown:

Scheme heave compensator cylinders
- 200 tons climbing crane
- 2500 ton Containerised floating sheerlegs
- Lifting FPSO modules up to a weight of 25,000 ton and more.
- MSG 100 3600 tons capacity.

### Capacity-table MSG-100 with MAINBOOM

<table>
<thead>
<tr>
<th>Outreach (m)</th>
<th>MAINBOOM</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
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</thead>
<tbody>
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<td>3600</td>
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PRELIMINARY
• Dusseldorf Mutifunktionsarena weight 1700 ton span 180 mtr.
• Shanghai Star project

Weights:
- Ferris wheel 1400 ton
- Leg supports 2000 ton
- Highest level 230 mtr.
ABSTRACT: Terneuzen- On the 14th of March 2003, the Westerschelde Tunnel was opened after a construction phase of five and a half years. The tunnel was constructed using modern technologies which were partially supported by software and other automated equipment. It’s uncommon to use highly automated technologies in construction projects because the unique character of projects reduces the economic feasibility of implementing automated techniques. In this article the following automated techniques will be described: measurement systems to measure the deviations of the used segments and the positioning of the Tunnel Boring Machine (TBM), and monitoring techniques with regard to the temporary frozen soil, which will be described in this paper. The saturation diving technique will also be described. The first part of this paper deals with the scope of the project and specific experiences gathered during the construction phase. The second part will deal with the automation techniques used will be described and finally a presentation of the conclusions will be made.

1. INTRODUCTION

The Westerschelde Tunnel is one of the longest bored tunnels in the world. What makes this Tunnel unique is that the deepest point lies 60 m below MSL (Mean See Level) and because the soil is mainly weak ground the execution was rather daunting. The tunnel connects Zeeuwsch Vlaanderen to the other parts of the province Zeeland and has replaced the ferry lines. The new connection reduced the crossing time significantly and a twenty four-hour-connection is possible. The tunnel consists of two parallel tubes with a length of 6.6 km. The tubes are connected to each other every 250 metres by a cross passage. Fire protection cladding was placed on the tunnel walls and the energy facilities are located in thirteen “cellars” beneath the road surface. In the event of a calamity, victims can reach an emergency substation every 50 m and call for further assistance.

The Main Contractor of the project was a Joint Venture (Kombinatie Middelplaat Westerschelde; KMW) consisting of five participants; Koninklijke BAM NBM NV, Franki Construct NV, Heijmans NV, TBI Beton- en Waterbouw Voormolen BV and Wayss & Freytag Ingenieurbau AG. From logistical point of view, the boring process was carried out from Terneuzen. During the boring process, on the other side of the Westerscheldt (Zuid Beveland) receiving facilities for the boring machines were constructed. A caisson was constructed and sunk to 42 m below MSL in the soil. The prevailing soil conditions in Zuid Beveland made this solution the best option.

Rings

As mentioned earlier the construction activities with regard to the tunnel were carried out from Terneuzen.
Therefore a site of about 300 ha was needed to carry out the boring process and support it. The contract required a hundred year life cycle and therefore meant that the basic construction of the tunnel had to meet stringent requirements. During the boring of the tunnel, rings were produced to form the tunnel. One ring has a length of 2 metres and consists of 7 segments. The last segment of a ring was a keystone, which completed a ring. Due to the high requirements (low tolerances in length and angles) of these rings and segments, the construction of the segments took place in a temporary concrete factory in Terneuzen, so the quality requirements and aspects could be kept under control. Approximately 53,000 segments were used in both tubes.

Due to the fact that the rings were constructed by seven segments and a keystone, tolerances of the segments were low, which meant that the quality requirements were more complicated. Tolerances, deviations and measure techniques are described later in this paper. After the segments are produced and approved for use, they are transported to the Tunnel Boring Machine (TBM). The heavy weights and large forms of the segments made it necessary to move the segments by train. A train traction of two 52 tons locomotives, 100 tons material and the transport equipment itself resulted in approximately 250 tons transport. The trains must cross the dike with a sharp curve and afterwards enter the tunnel on a 4.5 degrees slope. The original maintenance program for these locomotives wasn’t enough and after some near misses occurred, preventive maintenance was extended. Each tunnel tube was serviced by one railway with a siding every kilometre. Sidings were extended as well, so the delivery of segments could be controlled. Besides the delivery of segments to support the boring process, personnel and materials needed for other activities (cross passages f.i.) used the rails as well. Although originally only railway traffic was allowed.

Acceleration

After some major set backs occurred, and a delay of almost one year was estimated, KMW mobilised eighteen work groups to study the acceleration of the project. The main issue to accelerate the completion, was that the fitting out phase should be started during the boring process and that as many activities as possible could be carried out in parallel. This method was worked out in detail and the largest bottleneck that had to be solved, was the logistical support for all fitting out activities.

While the boring process could only be supported by railway traffic, it was necessary to allow wheel traffic in the tunnel as well. The use of wheel traffic in the tunnel caused other problems.

Formation of dust and the increased amount of carbon sooth in the tunnel were the important factors to deal with. Besides the boring process and the construction of cross passages, the main fitting out activities where:

- Construction of (Electrical) cellars
- Fire protection cladding
- Electrical & Mechanical Installations

As a result of the integration of the fitting out activities, the logistic movements in and to the tunnel increased while both access ramps had to be finished as well. Safety measurements for important facilities were temporary installed in order to be able to carry out the activities in this area. Fitting out during the boring process meant an increased number of employees in the tunnel. Due to the fact that the “climate” in the tunnel differs from the usual working area, safety facilities in the tunnel were even further extended. Additional education to the employers was organised and the success of the training became clear when a starting fire was directly smothered.

The effects of all measurements taken to accelerate the completion were great. The remaining (estimated) lead-time of three years was reduced to two years. All measurements, which had increased the costs for the Contractor, became economic feasible due to the fact that the terms of the contract were changed after the estimation of one year delay. A no-claims bonus system was added to the terms of the contract and additional investments could be made.

![Planning Westerscheldt Tunnel Project](image-url)

**Figure 2: Planning Westerscheldt Tunnel Project**
Segments

Due to the low tolerances of the segments, the requirements for the production system of the segments were high. The production system was intensively monitored by the QA department of the Main Contractor. Scrap had to be minimised, while the tolerances were decimals of millimetres. Angles had a tolerance of 0.1° degrees over a length of 2 metres! Many data had to be measured to decide if a segment is to be approved or rejected. Therefore it was necessary to purchase a highly sophisticated measuring system to cope with exacting demands. Due to the fact that approximately 130 segments were required to be produced each twenty four hours, the measure system had to be accommodated user friendly and above easy processing of the data.

Various measuring systems were evaluated and all advantages and disadvantages were carefully analysed. The essential requirements of the measuring system that the Contractor was looking for had to have:

- High accuracy
- Minimal disturbance to production cycle
- Easy in use
- 3D measurement
- Readily available

In the final analysis it was decided that a “photometric” system was the best solution according these requirements. Photometric measuring systems are very precise and easy to work with. As the system is independent of vibrations photos could be easily made by hand. Another advantage is that a measuring laboratory is not required. The Photometric system consists of:

- one digital camera (6.0 mega pixels)
- one laptop
- one orientation-stabilisation block
- one software module
- object marking points

Once a segment is ready to be measured, it is installed on the stabilisation block. After the placement on this block the object marking points are added on the segment. The more marking points are added the more precise the measurement is. After the pictures of the marking points are made with the camera, an infrared receiver on the laptop receives the transmitted data from the camera. After all the data is received the special purpose software module processes this data and carries out an analyses. The software can transfer the data to CAD stations when further processing is carried out. The analysis of the data is based on IST-SOLL. This means that values that exceed the “SOLL” value, the segment will be rejected as unsuitable.

Upper and Lower boundaries

As the segments are eventually fitted in place, it is possible that the linked segment of the same ring, or following ring can compensate the excessive tolerance of one segment. For instance a positive deviation of +0.8 mm can be compensated by a negative deviation of –0.5 mm. This making the overall deviation: +0.8–0.5=0.3 mm. Replacement of such segments is possible when the overall tolerance between two segments is less then the tolerance of one segment. This is only valid for segments of the same type (“Left” or “Right” rings and the same code in the configuration, A1-segment or C-segment). Therefore rejected segments, which failed the dimensional check, were not rejected. All segments were monitored by using a barcode system. Every segment has a unique barcode with all relevant data of the segments collected facilitating tracking of segments.
regular cycle. The primary review is carried out before the production is started. After a number of production cycles the secondary review was carried out. The review resulting by rejected segments was called the tertiary review.

**Positioning Tunnel Boring Machine (TBM)**

Due to the minimum tolerances of the segments and the minimum tolerance of the boring direction (10 cm on a length of 6.6 km!) an additional highly sophisticated measuring system was necessary. The differing curves in the tunnel alignment complicated earlier mentioned factors. As to reach Zuid Beveland within the tolerance, this could only be done by permanently measuring the three dimensions in which the TBM moves. To measure these movements of the TBM in the three dimensions, the position of TBM in relation to constructed part of the tunnel and the design axis is permanent measured. The so-called the design axis is programmed in the computer and with an automated measuring system the position of the TBM in relation to this axis (and specially the deviations to the axis) is measured, interpreted and corrected. The TBM moves by cutting the soil in front of the machine away and pushes itself forward on the last constructed ring by jacks. As soon as the tunnel moved two metres the jacks were rejected to build in a segment. The jacks were controlled separately and became the steering mechanism of the TBM.

**Measuring of the TBM’s position**

The positioning of the TBM was done by measuring the movements, compared to a (known) constructed tunnel (see figure 3). A Laser Receiving Shield measured the deviations, which was permanent installed at the TBM. At the rings a Laser Transmitting Instrument (LTI) was installed to shoot the laser on the LR Shield. On this shield, the movements of the tunnel in two dimensions could be measured. The third dimension was calculated by using the Laser frequency. The movements of the TBM, compared to the bored tunnel, were compared to the design axis and corrections could be made. Small deviations were automatically handled, and in the event another ring configuration was needed to meet the required design axis, the PC in the control room of the TBM automatically calculated the adjustments. Deviations were graded as major as soon the deviation was 10 cm or more from the design axis. In this case the computer calculated a correction curve with a radius of 3000 m till the design axis was met again. Due to the limited tolerances of the segments such a wide curve was necessary to maintain the required tolerances.

**Review of measurements**

Another issue to be considered were the (potential) movements of the tunnel. When, for example, the fixed LRS at the TBM moves in one direction and the tunnel with the LTI moves in the same direction, it appeared that no deviations took place elsewhere. To eliminate these failures, the last part of the constructed rings was daily measured following a strict protocol:

- Each 50 rings; every three days before tunnel boring
- Each 20 rings; daily before tunnel boring
- Each 10 rings; every 3 days after the tunnel boring, to review the settling of the tunnel
- Each 4 months; review measurements to check the settling of the tunnel
- In the event deviations exceeded the accuracy, this period of one year could be extended

At each 750 metres the whole fitting of the tunnel was measured. All these measurements resulted in a deviation of 2.0 cm for the Western TBM and 3.0 cm for the Eastern TBM. Both deviations were measured from the centre of the TBM. The fitting of both tubes related to each other was also measured. This measuring was carried out through the opened cross passages. To check the measurements of the Contractor the Employer had mobilised an external measuring company. This company measured if the deviations of the TBM’s measuring system were within the allowed tolerances.

**Saturation diving**

The geology of the soil beneath the Westerscheldt consists of different layers. The main layers are (different kinds of) sand and (Boom) Clay. Every layer has its advantages and disadvantages. Sand is a medium through which the boring progress is better as the fixed Boom Clay, but has a larger impact on the wearing factors of the bits and blades in front of the TBM. At a length of 6.6 km, bits and blades were periodically inspected and where necessary replaced. The deepest point of the whole trace was 60 metres below MSL, which means that the maximum local pressure in front of the TBM was equal to 7.5 bars. Execution of work activities at such a pressure level required the use of professional divers to carry out the inspection and replacement activities. Notwithstanding that the activities were carried out by professionals, one has to bear in mind that maximum saturation times are dependent on pressure tables. These tables describe the maximum processing time at a certain pressure. In addition to relative simple activities, divers had to carry out welding and cleaning activities with high-pressure tools as well. The high pressure made it necessary to carry out these activities by saturation diving. As this kind of work is unique in tunnelling business various safety requirements were put in place. These requirements weren’t limited to technical aspects only, the whole diving organisation had to meet strict requirements which in turn had to be approved by the Labour Inspection Services.

**Execution**

To reduce waste of production time, diving activities were carried out by two teams divided over a sixteen hours each working day. While decompressing is more time consuming than the increasing to local pressure, divers were transported out of the tunnel in a saturation transport capsule (l: 3.10 m; w: 1.50 m; h: 1.70 m) and shifted to a larger saturation space on site. On site two saturation tanks, provided with the primary needs for a living, was the recreation area for the divers when the other diving team was working. These tanks were under permanent control by medical specialists.

A working day of a diving team is divided as follows:

- Shift from saturation tank to transport shuttle: 1h
- Transport to the TBM and shift to the saturation area on the TBM: 1h
- Increase the pressure (by 2 bar) to local pressure in front of the TBM: 0.5 h
- Effective working time at the cutting wheel in front of the TBM: 4.5h
- Decompressing time by 2 bar in the transport shuttle: 2h
- Resting in saturation area on site: 16h

This production cycle was repeated till all inspections and replacements were carried out and the boring process could be continued. The longest “diving” cycle was ~21 days.

The specific circumstances that characterised these diving activities meant that special diving equipment was needed. Divers needed a mixture of three gases to breath (12% O₂; 48% N₂ and 40%He). To do so this mixture was connected by cables to the helmet. Diving equipment was provided by two connectors for breathing equipment, one water connector, to clean the breathing connectors, communication, light and depth measurement equipment and a video cable. To minimise illnesses and maximise hygiene, every diver had his own equipment. After each dive all equipment components were double checked with regard to the functionality and operational prepared.
In case of failures, the items were repaired or replaced. Therefore spare parts were held in stock on site to secure saturation diving wasn't postponed due to lack of spare parts.

The circumstances in front of the TBM were difficult as it was a dark area in which 55 kg cutting tools must be inspected and replaced. After a tool was removed, it was knotted on a line. This line had many knots to lift the tool up. When there were to less knots or the line was greasy, the tool could fall down and major injury to the divers down the working area could occur. Communication to the supervisors was difficult and a known “diving language” was used. Tools for example were classified by "1" for very good and a “6” for very poor. Major accidents didn’t occur, while at pressure levels of 3.6 bars or higher N₂ narcosis was monitored. An implication of such a disease is tire and divers start making failures. In 672 divings, only 3 decompression diseases occurred, which were all solved safely.

Saturation diving in tunnelling processes has proven to be a cost saving technique. Whereas Japanese tunnel contractors use several TBM’s to deal with the wearing problem of bits and blades, the Westerscheldt TBM’s were inspected by an innovative, preventative and timely replacement methodology that is far more economical in replacement costs and labour time then replacing whole new TBM’s.

**Cross passages**

As mentioned earlier in the introduction the tunnel consists of two parallel tubes linked every 250 m by a cross passage. The initial design was made with escape routes to the other tunnel tube every 500 m. Due to high level of accidents in tunnels during the design phase, the number of cross passages was doubled. A cross passage can be opened in case of emergency. The operator in the control room must unlock the doors as soon as he get a signal something is wrong in the tunnel. The cross passages have a length of approximately 12 metres and contains appropriate emergency facilities.

**Construction**

Due to the limited length of these “tunnels”, the link to the other tube was made by digging. Digging a hole in weak soil is only possible when the soil is temporary stabilised. There are different ways of stabilising soil and at the Westerscheldt tunnel, the soil was temporary frozen. To freeze the soil between the two tunnel tubes a kind of “heat”-exchanger must be temporary installed between the tunnels. To achieve this 22 freezing lances were drilled through the segments in the soil until they reached the other tube at a maximum distance of 20 cm. The internal distance between two lances was approximately 1 m. A liquid salt solution from –37°C was pumped trough the lances. The lance construction was designed to ensure that no chemicals would leak into the soil. The lances were drilled with an accuracy of 0.5%. Another restriction was that the drilling must be carried out with a minimum use of a half tunnel tube, to minimise disturbances to the logistics of the railway traffic. Besides the freezing lances two temperature lances and a de-watering lance were drilled as well. These temperature lances measured the temperature at two metres from the beginning of the frozen soil.

![Figure 7: Frozen soil](image)

To reduce the increased water pressure, caused by the frozen soil, the de-watering lance was drilled. All lances were drilled from the Eastern tube.

After the lances were drilled, the freezing equipment was connected. To reach the temperature of –37°C, a special purpose Ammonium based freezing machine was developed. The minimum amount of Ammonium was 80 kg and in combination with the limited space in which the machine is installed, additional safety facilities were also installed. Sensors measured the amount of Ammonium and as soon as the concentration exceeded it’s MAC value, the ammonium flow was closed and any leaked ammonium was neutralised by a water installation.

Approximately 26 temperature measuring instruments were installed in the Western tube facilitating a controlled formative of frozen soil. A mean temperature of -20°C and an ice thickness of 2 m must be strong enough to construct the cross passage. To reduce the waste of energy, isolation folie was placed inside both tunnel tubes to keep the temperature between both tubes low and no less heat exchange to the tunnels took place. Although most circumstances were known, some major safety facilities were installed. The largest is the emergency door in the West tube. The opening of a cross passage was all done from the West tube. As soon as the freezing installation had a blow out, this
emergency door could be closed and repair of the installation could be carried out.

Once the soil was strong enough (thickness > 2m), the soil could be removed. To remove the soil a special purpose cutting machine was developed. Every two metres progress, the opened part was sprayed with a 25 cm thick plaster. This was repeated till the East tube was reached. This layer of plaster was sealed with a plastic folie, which protects the cross passage against water. The last step was to finish the cross passage by a 40 cm reinforced construction concrete. The folie was covered by reinforcement and afterwards the formworks could be placed and concreting could be carried out. During the start of the drilling of lances till the end of drying period of the concrete the temperature was measured and controlled permanent.

All 26 cross passages were carried out as written above. The lead time to construct a cross passage decreased during the processing time and depends on the medium in which a cross passage is constructed and the depth beneath the Westerscheldt.

Another issue that became clear from this paper is that contractors should be aware of using innovative techniques. The use of saturation divers for instance, to carry out maintenance and inspection activities, in front of the TBM wasn’t carried out elsewhere in the World on such a scale as at the Westerscheldt Tunnel. Many preparations and studies took place before these activities could take place in a safe manner. Eventually using innovative techniques could save a lot of costs.

Cross passages constructed in Boom clay took more time to reach a 2 m thick Soil as cross passages in sand. The deeper the cross passage was constructed the less time it took to reach the necessary thickness.

2. CONCLUSIONS

The use of automation in project oriented production areas is increasing. Usually automation isn’t used at construction activities. The unique character and mostly limited scope of work (outsourcing of work packages to subcontractors) is the main reason for not even analysing automation systems. Actually in large scaled projects investments in automation systems can be very useful and economic feasible as well. In cases many different data must be stored, due to contract requirements f.i., the use of computer systems is very useful. Complex calculations, which must be carry out frequently, is also a good issue to analyse the profitability of automated systems.
Open Building as a condition for industrial construction

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ABSTRACT: Open Building advocates the direct relation between industrial manufacturing and the user / inhabitant. To make the industry-consumer relationship possible, base-buildings must offer space available for user controlled fit-out. To date, a fairly large number of experimental projects have been executed on a global scale. They demonstrate the potential of the approach. A re-distribution of design control involving all professional parties in the building industry is implied. To open this market, economic, legal, political, and bureaucratic policies must adapt.

KEYWORDS: Housing, systematization, industrialization, user control, design distribution.

1. INTRODUCTION

Open Building implies a two-fisted strategy. In a social perspective it seeks to respond to user’s preferences by offering flexibility needed for adaptation of individual units over time. In a technical perspective it seeks ways of building where sub-systems can be installed or changed or removed with a minimum of interface problems. These two goals clearly complement one another and cover an wide spectrum of expertise. Open Building is supported by designers, managers, builders, and manufacturers, who each see advantages in it for their own professional role. In the sixties, research at the SAR (Foundation for Architects Research) in the Netherlands proposed the separation of a ‘base-building’ and its interior ‘fit-out’ – the so called ‘support / infill’ approach - in pursuit of the same goals. True to its name, SAR focused on methods for design in open projects. The present Open Building network seeks a broader interpretation of the same principles.

Open Building as an organization is now formalized as CIB workgroup W104 which has a global membership and meets every year in another part of the world. To illustrate what the Open Building approach stands for, I will show some examples of what could be termed Open Building projects. Next we will consider more specifically how Open Building provides a context for the development and improvement of Industrial Construction.

2. EXAMPLES AND OBSERVATIONS

2.1 NEXT21 project, Osaka, Japan

An experimental building, known as NEXT21, was completed for Osaka Gas Company in 1994 in the city of Osaka. Prof. Yositika Utida, Japan’s premier authority on industrial residential construction, was asked to design the apartment building of the future. Not surprisingly, it contains the most advanced technology for the use of energy. Natural gas is chemically decomposed following principles first implemented for space craft. Solar panels are found on the building’s roof garden. Waste from inhabitation is entirely processed for re-cycling.

2.1.1 Open Building Principles

Utida decided NEXT21 should also follow Open Building principles and assembled a team of designers to do just that. Prof. Tatsumi and his younger colleague Takada in Kyoto University already had done several open building projects in the Osaka region. The office of Shu-Ko-Sha led by architect Chikazumi joined to do actual design work and Prof. Fukao of Tokyo University developed principles of modular coordination. This team, accompanied by experts representing the client, made a study visit to the Netherlands to see already implemented Open Building projects.
2.1.2 Three Dimensional Urban Design

The NEXT21 building demonstrates a clear distinction between ‘base-building’ and ‘fit-out’ following the SAR definition: the base-building serves as a collective facility, and the fit-out is different for each unit. The NEXT21 base building includes parking, pedestrian circulation both horizontally and vertically, and two public gardens, one on ground level and one on the roof. Utida declared the base building to be ‘three dimensional urban design’. Drawing the full consequences of this analogy, he invited thirteen different architects to design the individual units, in the way individual architects design buildings in an urban scheme done previously by another firm.

2.1.3 State of the Art Technology

The Utida team applied available sub-systems to fit out individual units. But it set down clear rules for separation of base building and fit-out to enable the new distribution of design responsibilities.

To facilitate this separation the base building offers not only empty spaces for inhabitation, but also a two feet double floor that can be reached by detachable floor panels and contains the infrastructure of utilities like gas, water, and energy as well as waste drainage. Fit-out can also use the double floor space to connect to these utilities and extend them throughout the individual dwelling. Like in urban design, the spatial hierarchy is matched by a hierarchy in the utility systems.

2.1.3 Façade System

The NEXT21 façade system was newly invented and considered part of the fit-out system. Providing aluminum panels and a variety of windows and doors, facades can be installed and taken apart without need for outside scaffolding, thus enabling easy adaptation later on.

2.2 Molenvliet project, Netherlands

The project in which Utida’s team was most interested when visiting Holland was in the town of Papendrecht, near Rotterdam. Designed by architect Frans van der Werf, the Molenvliet Project is considered the first true implementation of the SAR approach. Built in the early seventies the project had to follow the strict rules for public housing of the time. But by making the base-building / fit-out separation very clear in both technical and architectural terms, van der Werf successfully enabled the users to design their own. Here too, the technology was state of the art.
2.2.1 An Urban Fabric.

The Molenvliet project also can be called three dimensional urban design. We do not see separate buildings but a continuous ‘urban framework’ which forms courtyards interconnected by pedestrian alleys and accessible from the public street where cars are parked. Some courtyards are public and give direct access to the units on the ground floor while open public galleries lead to units on the second floor. Other courtyards contain garden space: both individual gardens for ground floor units, as well as collective gardens.

![Figure 4. part of the Molenvliet project, right: territorial subdivision, left: individual floor plans.](image)

2.2.2 Users Designing

Van der Werf allowed only two interviews with each of the user households to help them with their design. This proved sufficient. Because the units were for rent, cooperation of the owner of the estate, a non-profit corporation, was essential. Still, today, the management works in close cooperation with the users, and helps them adapt their unit’s interior layout and equipment.

[v.d.Werf]

2.3 A world wide trend.

Architect Frans van der Werf has recently completed his seventh Open Building residential project and is busy with the next. His Open Building projects are still much advanced in today’s practice, but no longer experimental. Nor is he the only one working this way in the Netherlands. The NEXT21 project has triggered a spate of Open Building Initiatives in Japan, most of which are supported by the government. Some are truly experimental, others already commercially viable. Finland also has government supported policies promoting Open Building in practice and in research. The CIB workgroup W104 on Open Building has members of these three countries as well as from the United States, Mexico, Canada, Taiwan, China, Hong Kong, Singapore, Germany, and other countries.

A world wide overview of Residential Open Building projects up to 1999 can be found in a book by Kendall and Teicher [Kendall] They list 131 projects, some twenty of which are shown in some detail. The book gives an overview of technical, economical, and management issues related to this approach.

2.4 Commercial Open Building

The practice of Open Building is already quite familiar in commercial construction. Office buildings are routinely built as base buildings in which entire floors are leased to the occupant and fitted out by dedicated fit-out contracting firms according to the design of dedicated fit-out designers. The shopping mall shows this distinction as well. The mall’s architect creates the public space in all its details, but leaves empty the retail floor space to be fitted out by specialized contractors serving occupant controlled design.

2.4.1 Residential Open Building Lagging Behind

In that sense residential Open Building is only doing what already is familiar in other building types. The reasons for this lag are several. Commercial residential projects, in contrast to the commercial office building, usually operate in a sellers market which leaves no incentive for innovation because the product is sure to sell anyway. Non-profit housing organizations have not much incentive either to delegate design responsibility to the occupant. Moreover, the fit-out of residential units is more complex compared to retail or office space. Kitchen and bathroom equipment in combination with general heating, ventilation, communication and power supply systems must be integrated in a small volume. Finally, we can note that in the practice of the office building and the shopping mall, the separation of base building and fit-out remains very much a pragmatic affair without much study or professional debate. There is reason to think that here too, performance is much lower than potential would allow.

2.5 A Direct Relationship

The examples given may illustrate that Open Building projects, both residential and commercial, combine two aspects. One has to do with hardware and entails the distinction of


separate configurations – base-building and fit-out – and the potential for their systematization and industrial production. The other is the distribution of design control: where traditionally the large project was under unified design control, now part of it is under control of a large number of individual occupants. Open Building sees the distribution of design control as a condition for systematization in the building industry: A clear base-building typology enhances systemic development. Most importantly, it opens a market for fit-out systems serving individual households, retail units and business entities. Conversely, further systematization of fit-out makes individual adaptation easier and therefore is an incentive for further distribution of design control. Open Building’s strength, ultimately, is that it brings industrial construction in contact with the individual inhabitant in a direct relationship without mediation.

2.5 Infrastructure and Consumer Product

This direct relationship is characteristic for contemporary industrialized society. The cell phone, television, the computer, our clothes and most other things we use daily are the product of it. The most prominent example is the automobile. Here too, a complex product is directly available to the user and its systematized production is now capable of making each car customized on demand. Surely, the lack of user control where residential construction is concerned is out of tune with contemporary society’s values.

More to the point, an industry serving the user often demands an infrastructure: The manufacturing of cars requires a network of roads. Similarly, use of the mobile phone demands many thin masts and satellites orbiting the earth. By the same token, when we think of the individual dwelling as an industrial product under control of the user, a shared infrastructure must provide the space for that relationship to be productive in. With the free standing house this infrastructure may be the land on which we build with the roads that make it accessible and the utility systems that serve it. In higher density conditions it must be the base-building.

3. THE SYSTEMATIZATION OF BUILDING

The systematization of building is accelerating. It is generally agreed that in the past two or three decades value added to the building by the manufacturer has been steadily increasing while value added by the general contractor has decreased proportionally. Designing a building has become an orchestration of available systems. Windows, doors, exterior wall panels and entire curtain walls, interior partitioning, floor slabs, elevators and stairs, balconies and banisters etc. etc. are all offered in manufacturer’s catalogues. Not to forget the various utility systems bringing power, gas, water and information in our homes and getting waste out.

Do-it-yourself outlets show us how many of these systems already have entered in direct relation with the lay person. In the North American continent almost the entire free standing house can be self built. In Europe, do-it-yourself retail provides all sub-systems needed for apartment fit-out. Initially, systematization was not intended to serve the self-help user. The employment of unskilled labor on site pushed the production of intricate parts to the factory. But what makes it easy for on-site labor, makes it easy for the user, and a new retail industry was born.

The most advanced example of environmental hardware as a consumer product is found in the kitchen systems that have come to permeate residential environment, particularly in Europe and Japan. You can select your kitchen parts in IKEA outlets and put them together all by yourself. Those reluctant or unable to do so, find dealers who are happy to assist their clients in designing their own, and send a specialized crew to install the chosen combination. Not so long ago, the kitchen used to be an integral part of the building. Today, in the Netherlands, no developer will any longer install kitchens in houses put up for sale: he expects the buyer to order his kitchen directly from a dealer.

3.1 An Open System

The Kitchen system itself is an Open system because it is a composite of autonomous sub-systems. In addition to cabinets it also includes a desk top with a sink, a cooking range, an oven, a dishwasher, a refrigerator and a freezer. It may include a hot water boiler and an exhaust ventilator. Further more we find in it lighting fixtures and outlets for electric power. The cooking range may be fed by a gas line and the sink needs to be connected to hot and cold water as well as a drainage system. The kitchen system designer may have designed the sub-system of cabinets, but all other parts have been designed...
and produced by other manufacturers who are not beholden to the kitchen system.

This openness has the advantage that a better sub-system can easily replace an older version, keeping the composite offering up to date. At the same time, the manufacturer and designer of, say, a faucet or dishwasher can compete for incorporation of their product in a wide range of kitchen systems.

3.2 Coordination of Parts

The coordination of so many products into a larger composite system is based on the simple principle that standardization must only deal with interface conditions. Where products of two producers meet, conventions of details and dimensions must be established. Beyond that, each designer is free to do his or her own.

This successful openness was not the result of top down regulation or a single invention, but the slow gain of practice. Over the years, the concept of a kitchen system became familiar to users and producers alike. Conventions of use and assembly became sufficiently stable for industry to formalize them. Social habit and consensus produced the sophisticated coordination we now take for granted.

3.3 Social Conventions

This is a lesson worth remembering: The systematization in building occurs when habits are formed and a way of working becomes generally accepted. Once a generally accepted routine appears, the door to industrial production of dedicated systems is open. It is often thought that industrialization shapes society, and of course that is true as well, but certainly in building practice, that is only part of the story. In the last century, countless inventions and proposals for building systems of all kinds have come to grief because they were not accepted by everyday practice. They demanded new ways of working but could not compete with already settled habits and customs. What eventually became successfully produced by the manufacturer was more often than not already done in the field, and industry seized the opportunity to do it better and more efficiently.

Today, after the upheavals and revolutions of Modernism, our ways of building and living increasingly show stable conventional patterns, often on a global scale. These patterns breed systematization and this, in turn, makes true industrial production possible. With as result the increasing industrialization we have noted.

When I speak of conventions and habits I do not mean only professional ways of working, but also the patterns of living of the inhabitant. It is in the latter that industry can establish the direct relationship with the user that already has been so successful in many other aspects of our lives. Thus we can distinguish two modes of industrialization in environmental production. The one which is most familiar serves the actual process of building. Here industry connects to the professional world to maintain a dialectical relationship with ongoing ways of design and management and on-site construction. The other, which is new, serves the user-inhabitant directly via dealers and specialized fit-out installers. Here, part of what used to be real estate becomes a consumer product, following a model already known in other aspects of daily life but not, so far, in environmental production.

The kitchen system is the most advanced example of that new trend. Bathroom systems may well be next. Eventually they will be combined in comprehensive fit-out systems as advocated by Open Building.

4. RE-DISTRIBUTION OF DESIGN CONTROL

If fit-out systems would indeed be available like cars are today, we would have a new consumer market that rivals that of private motor vehicles. Before we rejoice in this seductive vision we must ask ourselves how the base buildings will come about that must hold the countless fit-out units industry will make available to the individual user. One answer is that the product will trigger the infrastructure. When the car first appeared, the freeways were not there: they came later. As with the kitchen system, fit-out systems will eventually establish themselves and base-buildings will result.

This answer is attractive to those of us who like to design and invent systems and believe in the potential of industrial production. But others will point out that we inherited from Modernism a centralized design decision process that is well established among professionals who see no merit in changing it. In conventional residential building practice, the first thing to be designed is the floor plan of the unit. Once that is known, all parties can get to work. The structural engineer can design the load bearing structure, the consultants for utility systems can design the distribution of all manner of conduits through the building. Bankers can assess loans, developers can calculate expenses and profits, bureaucrats can give
permits. When we design a base building there is no floor plan. A new methodology of design and decision making is in order. But professionals, like normal people, prefer not to change their ways of working.

4.1 Systems design and Instance Design

Re-distribution of design control is part and parcel of industrial systematization. To make the kitchen system work two kinds of design are in order. There is the design of the system as such, and there is the design of the many instances of it. The two together make the kitchens appear in our homes. Hence we find a distribution of design control. Details, dimensions of parts, connections of parts, materials, textures, and colors of the parts, all must be decided by the system designer. His design decisions are general: they determine what all instances that can be made by combining the parts will share. In contrast, the design decisions pertaining to a single instance are unique because the user and the location are unique. This distribution of design responsibility allows industry to serve countless individual users.

4.2 A Matter of Policy

It is good to bear in mind that the examples of Open Building that I showed you, as well as all others that are on record, have been implemented in a state-of-the-art technology, without the benefit of any dedicated fit-out systems offered by the industry. In other words, these first experimental projects were demonstrations of re-distribution of design control first of all. They illustrate the power of the new game to be played. They also made clear how much easier it would be if dedicated fit-out systems would be available. It could not be otherwise: we have just seen how successful systematization follows already settled practice. If that is true, the issue of re-distribution of design in practice must be addressed head on to open the way for truly industrial fit-out systems.

Frank Bijlendijk, who runs one of the largest non-profit housing corporations in the Netherlands will tell you he does not think Open Building is a technical problem but a matter of re-distribution of responsibility first of all. He invested years of study and development to establish a policy where his tenants would be offered ownership - and hence full responsibility - for everything behind their front door. The housing corporation would be responsible for the building as a shared property of all inhabitants. Banks agreed to give mortgages to these new fit-out owners, the costs of which would be tax deductible like they are for owners of private homes.

Implemented on a national scale in the Netherlands, where the majority of households rent their homes, this would make a very large part of existing housing stock eligible for unit-by-unit renewal and renovation, creating a tremendous incentive for industrial innovation.

However, Dutch tax law was overhauled recently and no longer allows deduction of mortgage costs on fit-out ownership while maintaining the privilege for ‘real’ home owners. We may assume this sad case of discrimination was not the result of ill will, but of ignorance. Economists, lawyers, politicians, bankers, industrialists and other policy makers need to know what Open Building policy is about. In a few countries governments have begun to subscribe to this approach and support research and experimentation. Japan and Finland are among them. The Netherlands is one too, as you will hear from another speaker on this conference. But the need for re-distribution of design responsibility is not yet generally understood. Issues of Open Building policy are not yet topics of debate and study among professionals and policy makers.

But then again, as those who believe in the power of invention will say, once the car was known, the roads got built.

5. REFERENCES

[NEXT21], see: GA JAPAN Environmental Design, Jan-Feb 1994, and: DOMUS no.819, October 1999.


ABSTRACT: In construction production field, since various type of disturbance factor is existed, it is difficult to manage related information by using conventional model. In this paper, a new concept of “Parts and Packets unified architecture” is proposed. Data or information related to a product are carried by product itself and can be handled to manage whole system. It is a unified controller system which operates parts and packets together.

KEYWORDS: Glue Logic, Parts and Packets, Active Data Base, RFID, Automated Handling, Dynamic Scheduling

1. INTRODUCTION

It can be said in general that the construction industry is, regardless of its nations it belongs to, advanced or otherwise, of local character bounded to the narrower view on its marketplace, supply chain, and technology advancement. So fragmented are they, albeit of its huge market-size and opportunities, that it has been, in the aspects above, far behind the manufacturing industry like the automobile, aerospace, and many other manufacturers, lest to mention the IT industry. A major new initiative is underway here in Japan, aimed for breaking this socio-economical stillness and prejudice, stepping forwards to create a new industrial formation worldwide in this century. It is integration of “parts and packets” with a control mechanism of their dynamic flow throughout a perplexedly complex network of production in construction. We all realize this adventure may lead us to further advancement in incorporation of the manufacturing mechanism in our industry.

We all notice that the Internet has driven forcefully the way we do business and will continue to do so in the coming decades. It is the information network that has changed the surface of the globe permanently so that nobody can dream up even reversing it. However, what is flowing in the business of manufacturers and construction alike is not merely information, but more importantly the material flow. The supply chain network, in its broadest sense, is indeed the primary concern of our time that needs some paradigm shift as the Internet brought about for information. If there is a way where the information packets and material parts go around in hand with hand over the production network, and the information network and its material counterpart will be no longer considered distinguishable. If every one of the parts for assembly has a chip with antenna implanted which contains a unique address “Product URL”, it alone opens up a new horizon over which the two networks work together synchronically. The idea along this line is already intensively being studied by several research organizations over the world. It is as simple as the Internet, and yet it reaches the scope as wide and as deep as the Internet.

Coming around the corner is the technology that brings about another major impact on our way of construction business to some degree comparable as the Internet did. Given the new technology, we are most likely to be forced to restructure our product model of buildings, process model of construction, data model, construction management and the supply chain model, in short, overall business model for our construction industry. It will above all provide us with chance and opportunities to be able to solve the long-standing problems that have confronted us so long – implementation of manufacturing mechanism in construction.

2. SCOPE OF IMPACT

Of course even one large project cannot solve all the problems related to implementation of parts and packets integration mechanism in construction. We thus propose here for an International Platform of IT based reformation in construction under the banner of “Product URL-attached Parts Oriented Construction”. For the purpose to clarify and extend its unique characteristics further, here we describe some of
many possible applications at construction sites, not to restrict its much broader scope.

(1) **Quality Engineering**

Construction parts (building materials, components and parts) and design information are currently supplied to the construction workers separately. The skilled workers then interpret the drawings to map its graphic information to the construction parts available at hand. The current practice thus heavily relies on the interpretation skill of the workers, that induce uncontrollable randomness in quality achievement. If each part carries the relevant design information or can access to the remote servers swiftly via its address, the workers can retrieve only the relevant procedures necessary for its implementation. So that way an even unskilled worker can achieve precision works comparable to the manufacturing workers.

(2) **Life-cycle Engineering**

Two to three million parts needed for a building, depending on how to count, and yet the vast bulk of construction parts can easily be registered in and retrieved from D/B by this system. We thus can keep all the information of parts and their history in log. 80 –90 per cent of the life cycle engineering can be solved by this bulk of D/B. Parts comparability with this parts-level information retrieval will make possible replacement of parts in a building to its full extent, even perhaps structural modules, not to mention the infill. It will eventually erase the current dichotomy between renovation and newly-build in its entirety.

(3) **Supply Chain Engineering**

One can easily see the impact on the supply chain is far vast than ever achieved, for parts and packets (i.e. material and information) are no longer separable.

(4) **Construction Management**

This IT-based Parts Oriented Construction will allow the Cost Management to achieve its full transparency due to its accessibility to the parts-level information. For the design and execution are far more closely linked than ever achieved, controllability in Construction Management will increase drastically in result.

(5) **Inverse Manufacturing**

The Inverse Manufacturing is reverse processing from the artifacts to their components for the purpose of recycle and reuse. It moreover represents creation of a new industry to close the loop of industrial activities from the sold artifacts to the re-fabricated artifacts by reuse. The implementation of the Inverse Manufacturing however presumes the accessibility to the parts-level information of their material characteristics for recycle and reuse.

(6) **Standardization of Product Model, Process Model, and Parts Specification**

Though standardization of product model and process model is moving forward elsewhere, it is necessary to accelerate it and to incorporate parts oriented view. The IT-based Parts Oriented Construction and standardization activities of modeling will promote each other and provide each with solid basis. Standardization of parts specification will make it possible that parts can go around freely over the net and across the borders.

Though only a few of the possible applications were listed above, one may be able to see already the vast scope of its impact, only comparable to the Internet revolution. It is not a mere replacement of the existing technology by a new one, but a paradigm change, that requires or induces the industrial rearrangement across the world. This depth it can reach to and this scope it can span over may require an international collaboration program.

3. **DYNAMIC CONSTRUCTION BY INTEGRATED PARTS AND PACKETS**

Control of construction process must deal with a bulk of scheduling elements that are produced by multiple heterogeneous players, contractors, sub-contractors, and parts makers. Their scheduling elements are necessarily intermingled and linked with each other. The whole schedule is managed and adjusted as one giant flow of processes. One small change in a tiny part of the whole schedule may possibly propagate its influence into the whole [1]. Every such complex system which is non-linearly linked often shows some chaotic behavior at worst, and leads to a catastrophe. Upon this peculiar condition, construction process management is conducted on site holistically at every moment from the commencement and completion of a project.

There are variety of causes that force scheduling change. It is of critical issue when a signal of change is dispatched within a complex system. If timing gets lost, disastrous consequence
may result with severe cost loss. It is also critical where a change occurs among multiple players, as well as what happens. The Parts and Packets Unification System (hereafter called PPUS) allows parts or units to signal change in their attributes, as they go through the complex production system (Fig.1).

In a factory, production facilities like cells and stations are positioned at rather fixed location and are linked by information network. Whereas, at a construction site, most of facilities are temporary, mantled and dismantled cyclically, and are changing their locations continuously. It is not a trivial matter to link these temporary facilities by information network. In a factory, a pre-processed product is gradually processed in sequence as it passes through cells, stations, and lines. In another word, the frame of coordinate to detect the current status, position, and timing of parts is fixed, while the frame of coordinate itself is changing in the case of construction, for the production environment is metamorphosed as a building is being built. What was built till now interferes with what to be done. This dynamic linkage between the production environment and processing makes it subtle to network product, process, and its environment.

An intelligent construction method is not perhaps possible to its full realization, unless it succeeds to adapt these inherent non-linear coupling within the system, either in scheduling or in actual processing. PPUS is one possible solution, for chip-implanted parts behave as if they spontaneously send messages to their proper addresses, whenever their state are changed, and move around freely within the production system as if each of them provides its local coordinate of reference.

4. GLUE LOGIC AS CONTROLLER FOR BUILDING WORKS

Millions of chip implanted parts move around in a complex production system of construction under the scheme of PPUS. As they are assembled, their attributes may be altered. Some controller is required to orchestrate their movement.

The controller system named "Glue Logic" is an infrastructure system which is designed to make building manufacturing work control easy and flexible [2]. This system binds multiple application software modules, referred as “agents”, developed and compiled separately, and coordinates those agents by means of inter-process massage passing. As the Glue Logic supports event notification and condition monitoring features based on active data base scheme [3], users can easily build real-time event-driven application agents. Each agent is free from polling shared data, waiting for notification messages from the Glue Logic.

As all of the data and agents in a system are abstracted, and are handled with symbolic names defined in the Glue Logic, agents can be built without any knowledge on implementation of others. Each agent in an application system can be developed concurrently, and can be added, deleted or changed freely without modifying other existing agents. As the result of these, the Glue Logic compliant agents are easy to re-use, and the users can build large libraries of application agents. Some agents having rather general purpose may be shared among various users, the life cycle and the reliability of such agents are extended, and the cost for software development is greatly reduced. Above all told, the Glue Logic can be realistic controller of a complex system of PPUS.

As shown in Figure2, the Glue Logic consists of two major parts: the communication interface subsystem and the data management subsystem [4]. The communication interface exchanges information with agents running in both the same work-cell controller and remote work-cell controllers connected with the network system. The data management subsystem consists of also two parts: the data change monitor subsystem and the data storage subsystem. The data storage subsystem manages the association pair of the name and the value of the object. The data change monitor subsystem monitors the changes in the data storage subsystem and sends out the data.
change notification messages, and executes depending data evaluation.

Figure 2. Configuration of Glue Logic

5. IF7II PROJECT

IF7II project started two years ago in the framework of IMS (Intelligent Manufacturing System) program. The objective is to develop the PPUS system and implement it in actual practice. Figure 3 shows the scope of research.

Three companies are involved in its implementation, Shimizu as general contractor, Tostem as sub-contractor and maker, Hitachi Zosen Information System as solution business. Figure 4 exemplifies its partial system developed and analysis conducted.

Figure 3. IF7II IMS Project and Its Scope

5.1 Construction Management via Gates

It is adequate initially to implement PPUS from bottom-up as it is an extremely distributed system for building production. First, PPUS is viewed from a parts-maker’s point of view. Activities of building parts maker are engulfed in a much larger complex whole of activity network on site. A maker manages its production process, and responds to changes required from the larger flow. Some change often propagates its influence on multiple subcontractors who are linked each other, and causes loss of cost among them, potentially, at worst, resulting in exponential blowout.

We identify the points in process where outbreak of cost increase is likely, and then set them as gates. The main stream of a maker’s process comprises of “Contract”, “Design Approval”, “Manufacturing Preparation”, “Product Drawing”, “Production Plan”, “Manufacturing” (cut, fabricate, assembly, curing), “Shipment”, “Installation”, and “Delivery”. The sub-process from “Design Approval” to “Shipment” is solely within the maker’s process which remains a black-box for the construction site. However, this sub-process is one of primary sources of cost increase. The Glue Logic system monitors and supervises the sub-process by checking the gates, even though parts are not yet formed. In another word, the gates are virtual entity that sends message about not-yet-formed conceptual parts, when they pass the gates.

Once parts are manufactured, chip-implanted parts are shipped to a construction site, assembled, and installed on site. As parts are dislocated in space and time, and/or reconfigured as integral part of a building under construction, simple act of reading the product URL on chip triggers to change the attributes of these parts in the data management sub-system of the Glue Logic. Once the parts’ attributes are changed, that triggers to send message to the pre-assigned addresses if a simple logic attached to the data point is satisfied. Each data point therefore contains attribute, simple logic, and address. Millions of data points are passing information each other. This very bulk of acts of passing and receiving dynamically change the state of the whole data base. Hence the data base behaves like an autonomous giant controller.

5.2 Construction Management via RFID

<Parts Management>

Figure 5 shows one type of chip made by Hitachi, called \( \mu \)-chip. Its size is quite tiny of a micron. Attached to it is electromagnetic induction coil or antenna. When a chip-implanted part passes through a gate, the gate reads the Product URL of the part. It determines what it is, where it is, when
it is as well as in what state it is. The corresponding data point in the Glue Logic is then altered, which generates an event and a chain of succeeding actions.

It is expected that the size will soon be reduced down to nano dimension, given the recent quick development of Nano Technology.

The construction workers carry a PDA which is capable of read/write on a chip attached to parts (Fig.6). They can retrieve handling manuals, drawings, installation sequence, and other relevant information about parts, when needed. This handy digital equipment allows even an unskilled worker to perform a quality work. Upon completion of installation, workers dispatch a message of completion to the Glue Logic. This allows concurrent management of completion of works. Moreover, if a worker read the chip both at the commencement and completion of work, the exact work period is automatically calculated and recorded in log. This simple mechanism leads to a vast consequence such that we automatically obtain a work period of every construction work, and the resultant data enables a scientific approach to construction work.

Construction scheduling is an integral complex whole of sub-schedules for contractors, subcontractors, and makers [5][6]. A master schedule is made for on-site schedule as a global schedule.

Source of change in scheduling exists everywhere among the multiplex of schedules, lying layers upon layers. Dynamic scheduling becomes possible in the Glue Logic architecture, for the component schedulers are considered independent objects of time management which send messages of requirements of schedule change to each other and respond to the others’ requirements. However, it is not always possible to satisfy all the requirements of schedule change, because of
possible conflict among these requirements [7]. Unsolvable conflicts may demand remodeling of product, process, or facility (Fig.7). Switch to remodeling from rescheduling is automatically done by the Glue Logic controller.

<Automated Handling of Components>

Figure 8 shows a relation between construction robots, construction components, and their information. A robot can acquire information about the required task and about the component via RFID attached to the component. Then it accomplishes the task in compliance with the retrieved information: First, the robot acquires an ID from RFID device attached to the component. The robot sends the acquired ID and the required task to the operation server, while achieving the task. The operation server creates required information for achieving the next task using the ID and sends the resultant information to the robot. Meanwhile, the operation server updates the component data according to the task results. The communication between the robots and the server is a LAN network or the Internet.

As shown at Fig.9, the robot obtains the ID from RFID device attached to the component if the ID device is within the communication area of the ID reader.

6. CONCLUSIONS

Robotics Construction in this century may be transformed into more subtle form. The whole construction process is regarded as virtual “Robotics” which is controlled by a giant controller. Parts and packets are unified. The components to be controlled have both information and physical aspects within their integrity. The controller is a transmuted “OS” (operating system), which operates both packets and parts.

Acknowledgement

This work is supported by IMS International Program IF7-II.

7. REFERENCES

EU FutureHome Project Results

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ABSTRACT: The EU FutureHome project is focusing in the development of new modular building construction with several important features: high quality, variety of designs, mass production, reasonable cost, and etc. To reach this objective three main points can be study: a) integration approach during all the stages of the building design (from architectural design to civil engineering), b) standardization of the parts, the assembly technology, the joints, etc., and c) industrialization of the parts production. In this way, the main objective of the FutureHome project is the development of Integrated Construction Automation (ICA) concept and associated to them technologies during all the stages of the house-building construction process. This paper presents the main results of the EU FutureHome project focusing in the design, planning and on-site building erection processes.

KEYWORDS: Modular construction, integration, automatic design and planning, automatic assembly, robotized construction.

1. INTRODUCTION

The main objective of the EU FutureHome project is the development of Integrated Construction Automation (ICA) concept and associated to them technologies during all the stages of the house-building construction process [Balaguer 2002]:

- Design the buildings in modular way taking in mind their robotic erection.
- Automatic planning and real-time replanning of the off-site pre-fabrication, transportation and on-site assembly
- On-site automatic and robotic transportation and assembly of the buildings’ pre-fabricated parts.

Nowadays methods on house building are based on manual techniques that are slow, expensive and non-coordinated. Each building continues to be unique in architecture and construction sense. Even though the investigation to develop new construction techniques has been important during the past years there is still a long distance between the construction industry and others industries, such as automobile industry. It is difficult to image houses being produced in the same manner as cars, but, at the same time, it is not possible to construct the houses as eighty years ago.

A change in the construction methods and the acceptance of the high quality and flexible prefabrication technologies are essential for the construction industry. The challenge of this project is to automatically build different houses with the same pre-fabricated modules [Balaguer 2000]. The benefits of construction industries can be improved by using advanced manufacturing systems. These modular systems will increase the quality and the customer satisfaction.

This idea of the modular house-building is not new. Several developments were done in the past [Naja], [van Gassel 1996]. Some of them were used in massive way in Eastern Europe, Germany, Japan and other countries. However, all the past approaches didn’t solve three main problems: a) quality of the modular houses, b) flexibility in the design, i.e. different interior and exterior designs are made by the set of predefined modules, and c) robotic on-site assembly of modules. The EU FutureHome project tries to avoid these disadvantages introducing the ICA concept.

2. MODULAR CONCEPT

The objective is to erect a building complex that consists of a set of buildings. Each building is erected using 3D modules and 2D panels (facades). These modules and panels are prefabricated off-site in a factory. Using beams, panels, installations elements, etc., 3D modules are assembled in a flexible production line.
Frames, panels, windows, doors, etc., are used to build the 2D facade panels. The architectural design carries implicitly the idea of singular buildings. This idea is not compatible with automatic mass production of modules. Making a reduced group of modules for each building may not be viable, but using ample catalogue of available modules should be sufficiently to prevent the limitation of the designer’s creativity. The solution should be a commitment between both ideas. The first step is the selection of the main module with the standard dimensions which can be slightly adapted if necessary.

To define the 3D modules size several features can be taken in mind: a) maximum dimension for factory manufacturing, b) maximum dimensions for truck transportation, c) maximum payload for the on-site assembly machines, etc. As an example, in the FutureHome project for the ensuits, cloaks and bathrooms the 2.4 x 2.4 x 3 m (l x w x h of external dimensions) size is selected, and for the stair case 2.4 x 4.8 x 3 m is selected as a double module. The 0.3 m grid is used for small modifications of the module. The CAD based designed modules can be manufactured in mass production way. An example of this technology is the Japanese 3D modules manufacturing. The modules are produced and equipped in factory like the cars in the automobile industry. The modules include all the external and internal elements, including power wiring, water pipes, etc.

One of the most important aspects of the developed modules is its possibility to be automatically assembled. For this purpose several assembly connectors were developed for: a) assembly modules itself, b) structural connection, c) electrical and d) service pipes connections [Bock]. These connector permits to perform in automatic way the complete assembly between modules.

3. DESIGN PROCESS

How will modern modular houses be automatically designed using the ICA concept? The process starts with the user’s demand. Different users (a construction company, a real estate or a final customer) have different necessities: detached houses, semidetached houses, row of terraced houses, apartment blocks, etc. Other important difference is the quality and type of materials employed in the construction, which is conditioned by esthetical preferences of the customer and by economic factors. According to the customer specifications the architect can design the building by two different methods. The first method is based on a traditional architectural design, which is commonly performed in 2D. The architect designs the building without knowing that it will be constructed by modules. Then, this traditional design will be adapted to modular design using specially developed AUTOMOD software package [Diez]. This package transforms the 2D drawings into 3D ones and automatically performs modularization of the building. The modularization can be divided in two parts: the calculation of the interior 3D structure and the division of the external walls in 2D panels. During the modularization process, continuous adjustment of the modules sizes has been performed using several criteria: maximum number of the same modules, maximum volume of the module, transportability of the modules and many others.

![Figure 1. Examples of modularization criteria: a) criteria 1, and b) criteria 2.](image)

An example of this procedure is presented in the Fig. 1 where different modularization criteria have been applied: a) Criteria 1: modularization taking into accounts the underground parking columns.
and vehicle circulation between them, and b) Criteria 2: one module for one room.
In the second design method, the design is performed using a catalogue of 2D and 3D modules. An architect selects the modules from a library to design the building. In this case, it is not necessary to calculate the modules; the list is directly obtained from the drawing. The modules’ catalogue is updated with new modules or modifications of existing ones. The factory provides information about modules, materials, accessories and fabrication techniques, which is employed to add new elements into the modules’ library.

The crucial point is the definition of the set of modules to be used. The geometry of the modules must permit to design a lot of different houses (exteriorly and interiorly) with the reduced set of modules. This idea leads to the compromise between architect (responsible of the design stage) and engineers (responsible of the pre-fabrication and on-site building erection stages). For more variety of designs more different modules are needed and for higher factory productivity of manufacturing modules less different modules are needed.

A specific tool for general purpose AutoCAD™ system has been developed to assist the architect in the above described design procedure. These process-oriented utilities are based on the dialogue boxes to guide the design process in an easy and friendly way. The designer follows the indications given in the dialogue boxes to define the module characteristics. Finally, the module is included into the drawing.

4. PLANNING PROCESS

The planning process is one of the important parts of the ICA concept. Its efficiency depends the productivity of the whole construction process. The planning process consists of three basic modules: a) planning of the off-site factory for pre-fabrication of modules, b) planning of the transportation, and c) planning of the on-site building construction by assembly the modules. In construction of the high rise apartment or office houses field factory is necessary. Its main mission is the on-site assembly of macro-modules (big structures, blocks, etc.). In this case the field factory is included in the planning process.

The planning process uses a layered architecture. Each layer plans the activities of each construction stage. The layers contain the planning procedures, the planning tools, the software applications and specific formats for their exchange. The use of a layered architecture does not imply that layers planning procedures are completely isolated. It can be necessary to establish global goals for the whole planning system. For example, in the case of modular construction it is necessary to decide what fabrication sequence is globally the most effective. In this way it is necessary to calculate: the optimum sequence for the whole off-site factory, the optimum sequence of the transportation, the optimum sequence of the field factory and of the on-site assembly processes.

The off-site and field factories planning are performed using well known CIM concept [Peñin]. Each factory plans and controls the output sequence of fabricated modules taking into account not only the time dependent manufacturing and transportation aspects (like, just in time or others) but also several aspects related to the market, legal and economical requirements. The relationship with the suppliers is also very important part of planning process.

One of the most important layers is the on-site assembly planner. The on-site assembly processes have been performed by robots and by automated machines, like autonomous cranes, etc. In this case the on-site planner is a 4D one, taking in account not only the geometrical constraints of assembly but also the time constraints. This layer determines the sequence in which different building components are assembled and it plans the robot or crane trajectories for assembling them.

![Figure 2. AUTOMOD3 lanner for the on-site processes.](image)

The developed AUTOMOD3 tool is a visual editor running under ObjectARX™ AutoCAD™ environment. Fig. 2 shows an example of the
planning procedure for the on-site assembly of “Row of houses” [Padron]. This tool allows the integration of the planning subsystem with tools like the ACIS™, OSCON™ (architectural model) [Trasey] and the AutoCAD™ Architectural Desktop, among others. The communications can be by DXF files of IFC protocol.

5. ON-SITE ROBOTIZATION

Manipulation and assembly procedures in construction industry are totally different from other sectors, such as traditional industrial sectors (automobile, electronics, etc.). Industrial robots has a limited working area (some meters) and its payload is normally not very high (some tens of kilos). This leads to high speed and very high positioning repetitivility (tenths of millimeters) of industrial robots. Robots in the construction industry must have totally opposite features: very big working area (tens and even hundreds meters), very big payload (hundreds of kilos and even tones) and it is not necessary to have very big positioning repetitivility (some centimeters).

During the last years some robots of this type have been developed. The most relevant examples are the ROCCO [Balaguer 1996] and the BLR [Heintze] robots for brick assembly. These robots were specifically developed for masonry tasks and looks like a mobile crane. They are hydraulically driven and its maximum payload is 300 kilos. But for the assembly of big 3D FutureHome modules this payload is not enough. For this purpose other alternative was checked during the last years. The idea is to use the conventional construction machinery, like tower and gantry cranes, and transform them into robotic devices. Some examples of this type of robots are [van Gassel 1993] and [Tomczyk]. Nevertheless, its features and its control strategy were not sufficient for the precise and fast assembly of FutureHome modules.

For the manipulation of the heavy 3D FutureHome modules (some tones) and for its on-site assembly with small positioning tolerance (about 5 centimeters), the most adequate crane is the gantry one. It has a very good mechanical rigidity and sufficient speed. Nevertheless the steel cable transmission in vertical (Z) axis is a very big disadvantage which create swinging of the load (module). This withdraw must be solved by adequate control strategy [Garrido].

The main idea is use a low cost commercially available gantry crane and then transforms them into robotic system by the following modifications:

- Introducing of the AC brushless servomotors in the entire axis.
- Introducing the vector control drivers for all motors.
- Introducing position sensors (resolvers).
- Introducing the PC control system based on the multi-axis control board.

In this way the gantry crane is transformed into 3 DOF robotic system. For Lab test the 1:3 scale system and modules are developed (Fig. 3). The movements in X and Z axes (trolley movement and elevation) are controlled by one motor each, but in the Y axis (bridge movement) it is necessary to motors: Y1 and Y2. These two motors have it own control loop. To obtain the rectilinear movement of Y axis the synchronization of Y1 and Y2 axes is performed by hierarchical master-salve strategy: the Y1 is the master reference and Y2 is the slave follower. This strategy guaranties the non misalignment of the gantry’s bridge.

The system is equipped with two types of sensors for assembly procedure: two cameras and one 2D inclinometer. The software architecture is formed by different software modules used in the control and the monitoring modes. The main program calls the modules in a synchronized manner using the priorities and semaphores. In the case of the multi-axis control board the communication is performed in form of character strings with special meaning to the card. These commands are calculated through a control algorithm to avoid undesired swinging of the load and taking into account the sensorial information of the whole system. Among the different modules, the User
Graphical Interface represents the main interaction gate between the operator and the crane. It allows the Tele-operation of the crane as well as the execution of programs in a fully automatic mode. The programming module helps the user writing and loading existing programs from project databases. Sequences of module assembly generated by the planning tools, mentioned in previous sections, can be loaded from the database of a given project and interpreted to the crane programming language.

6. MODULES ASSEMBLY PROCESS

The correct positioning and assembly of modules is one of the most critical processes during the building erection. Normally this operation is performed manually with several disadvantages: a) a big dangerous for human operators, b) a high number of involved operators, and c) a low productivity. The automatic assembly of module by robotized crane is very convenient and avoid the bellow mentioned withdraws. Nevertheless for correct automatic assembly of big and heavy modules the following elements must be introduced:

- Assembly connectors development
- Grasping mechanisms development
- Sensorial system integration
- Anti-swing and control strategy

Due the fact that assembly is performed by robotized crane in vertical direction, each FutureHome module is equipped with assembly connectors in each corner. The geometry of these connectors are male and female cones (Fig. 4). This type of connectors permits to perform the assembly process with a big tolerance, about 5 cm, sliding one female part through the male one. For correct sliding of female connector through male one the force analysis during assembly may be performed. The analysis is based on the forces reactions. As a result of this analysis, the exact geometry and material are selected. Supposing that the modules cross section is 100 mm (laboratory size), then we choose the connector bottom base to be this size. For the angle size we have to reach an agreement. It has to have the adequate size for sliding and to avoid jamming and wedging. We come to the conclusion, by force decomposition, that $\mu = \tan \theta$. Therefore, knowing that our scaled modules are made of Aluminum $\mu = 0.47$, the connectors angle has to be at least 25°. To make things easier we choose a $\theta$ value of 45°.

7. CONCLUSIONS

The FutureHome project develop and introduce a new integrated concept for automatic modular construction using integrated approach. All the stages of the processes are integrated in the same programming environment and have coordinated communications.

As the demonstrator of the project, a real residential building was built in Ijmuiden (The Netherlands) by CORUS, one of the industrial partners of the project (Fig. 5 and 6). The building includes most of the developed technologies and concepts of the project. The used materials are mainly lightweight steel, aluminum, wood and plastics.
8. ACKNOWLEDGEMENTS

This work is supported and funding by the EU under BRITE-EURAM program. The author wants to than all the FutureHome partners (http://www.cv.ic.ac.uk/futurehome) for their important collaboration. Special tanks for the research team of the University Carlos III of Madrid: Mohamed Abderrahim, Ramiro Diez, Victor Manuel Padron, Antonio Gimenez and Santiago Garrido.

9. REFERENCES


IFD Building in Europe
A blueprint for production and delivery of customer satisfaction oriented buildings

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ABSTRACT: This paper discusses the advanced concept of Industrial, Flexible and Demountable (IFD) building. The IFD concept aims to balance the interests of all construction industry stakeholders. The use of industrial building methods for offices, schools and factories has gained broad popularity in the practice. However, the building clients conventional view does not give high appreciation on uniformity in terms of modular and industrialised components of architecture. Besides, the fragmented nature of the construction sector, which concentrates mainly on cost-based competition, provides little incentive for innovations. The office of Damen Bouwcentrum in Delft can be considered as a breakthrough out of the traditional culture in the construction industry. The IFD based office building received the grant from the Dutch innovation programme. It has been presented as a response to the changing market, from supply-driven to demand-oriented. It is an example of projects where the construction industry is encouraged to cooperate in the search for better alternatives. Based on the experiences in the project and being inspired by the exploration of the IFD market potential, a European research project has been conducted. The project results in:
- an IFD organisation model, based on comakership;
- an IFD process protocol for the development, production and delivery of IFD buildings, and
- a system morphology for IFD buildings: dwellings and offices.
The implementation of the IFD concept into the traditional construction industry is not simple. The Dutch IFD programm demonstrates the availability of innovative technology. The real bottleneck appears to be the organisation of the construction process. Implementing the concept of co-makership will bridge the gap and lead to a substantial breakthrough in the construction industry.

KEYWORDS: building process innovation, industrial, flexible, demountable, customer satisfaction, collaborative engineering, comakership, product development

1. INTRODUCTION

IFD Building stands for Industrial, Flexible and Demountable Building. Originally IFD is a Dutch construction innovation programm, challenging the construction industry to improve their overall performance. Some characteristics of IFD are summarized in table 1 (Source, v.d. Brand and Vos; 1999). The primary motive for industrial building is the improvement of the building production process. Flexible buildings aim at the fulfilment of the user’s demands and wishes at the first delivery of a building and the following periods. The primary motive for demountable building is reducing environmental pressure. Industrial, Flexible and Demountable construction principles are not brand new. For some time, innovative designers and suppliers have been active in developing new industrial concepts and products for the construction industry, which could justifiably be included into the IFD category. However IFD has a Dutch origin, its potential certainly reflects the whole European construction industry.

1 IFD Building is Industrial, Flexible and Demountable Building
2. EXPLORING THE IFD MARKET POTENTIAL

In 1997, Damen Consultants carried out an investigation into the market potential of IFD Building (Damen 1997). The Dutch Ministry of Economic Affairs published the results. The main conclusion that came from this investigation was that IFD building principles embodied an integrated concept, which could unite environmental and economic interests by offering creative solutions to the use of raw materials, labour and technologies. IFD balances all construction industry stakeholders’ interests (figure 1).

Until now, however, these developments seem to come to an end after the one-off application of IFD concept or product in a single project, and it has not been proved possible to take the next step to products, which are totally unrelated to a specific project. The construction industry is not used to project independent innovation and long-term co-operation. They spend no more than 10% of their annual turnover on R&D, and even then most of that investment can be attributed to the suppliers. The fragmented nature of the construction sector, with many small businesses, and the way in which tendering is mainly concentrated on cost-based competition, provides little incentive for innovation. The European Commission’s report on the competitiveness of the construction industry (EU 1997) shows this applies to the construction industry all over Europe.
3. IFD EXPERIMENTAL PROGRAM

As a result of the exploratory study, the Dutch government started up the IFD (Industrial, Flexible, Demountable) building program. Their aim is to promote the application of IFD construction principles by the industry and the market, so that the method can become embedded in conventional building practice. It must demonstrate it is possible to build more consumer-oriented, with better labour conditions and deliver a higher building quality.

The initial acquisition of projects took place in the spring of 1999. From each tender, the best and most renewing projects will be selected as demonstration project. The project-tenders of 1999, 2000 and 2001 together acquired 286 project submissions, 71 demonstration projects where eventually selected. They serve to demonstrate innovative applications of IFD technologies, for new construction and renovation, public housing and utility building projects. The intention of the demonstration projects is to stimulate other parties to make use of IFD techniques. The last round of acquisition will take place in the autumn of 2003.

3.1 IFD example project: Delftech Office

The office of Damen Bouwcentrum and ABT was one of the granted IFD projects in the first round. This provided the opportunity to put the IFD ideas into practice. The intention was to develop a prototype for an office for SMEs. For that purpose a consortium of designer, contractor and suppliers was set up. The design starting points were: long life, loose fit, low energy and less waste.

The IFD Delftech Office consists of two office-wings, separated by an atrium. Car parking is provided on the ground floor. If this parking is redundant this space can easily be transformed into extra office space. Also an extra floor can easily be added, and for that purpose the load bearing structure can be reinforced later on (long life). Most building parts are produced industrially an assembled on site. The load bearing structure consists of prefab demountable columns and beams of steel and concrete. The prefab and demountable floor elements are made of concrete, extra span cables and reinforcement strips enable to carry additional load in time (figure 2; loose fit, less waste). The building has double façade, the internal one consists of interchangeable (open and closed) parts, while the outer skin is fully glazed with a sunscreen for cooling (figure 3). The shaft in-between is ventilated (low energy).

When the aspects of ‘industrial, flexible and demountable’ are considered, the process can be evaluated as partially successful. Some new innovative solutions that fit the IFD concept were successfully developed and implemented. However, the construction process itself took more time than originally planned (+50%). In addition to this, the mutual collaboration in the design phase of the project was disfunctional. The result was a change of contractor in the building team. At the end, most of the actors were satisfied about the result, but the client was less satisfied (van Gurchom, 2002).
3.2 IFD program first results

While there is plenty of interest in IFD construction products and ideas from the supply side, there still is little interest from the market, and IFD construction principles are still far from becoming the daily practice in the construction industry. In recent years, however, the users of buildings have become more outspoken, and the requirements and wishes they are now expressing display far more dynamics and variation than ever before. At the same time, the market is changing from the supply-driven one to the demand-driven one, and these are compelling the contractors to seek new alternatives. At this point, Industrial, Flexible and Demountable construction techniques can meet the expectations and offer many advantages.

4. IFD BUILDING IN EUROPE

4.1 Project outline

Based on the experiences with our own office and inspired by the exploration of the IFD market potential we have defined a European research project to conceptualise and develop the organisational, technological and commercial framework and supporting communication/information system to deliver client-oriented Industrialised, Flexible and Demountable (IFD) Buildings – in short IFD Buildings. The research consortium comprises all key building partners: principal organisation, architect, contractor, service contractor and research institute, from Italy, Finland, France, The Netherlands and the UK. The project results are:

- an IFD organisation model, based on comakership
- an IFD process protocol for the development, production and delivery of IFD buildings, and
- a system morphology for an IFD buildings: houses and offices.

4.2 IFD organisation model

The IFD Buildings project starts from the initiation of an IFD co-maker consortium. IFD partners will collaborate in a long-term relationship and build upon mutual knowledge and experience. They will invest in market research and image-building around their product brand. At the same time they will explore possibilities to establish long-term relationships with their customers (‘join the IFD family’). For this purpose an integral organisation model has been set up, containing 4 main clusters: market research, product development, production and sales (figure 4). Within these clusters the essential processes supporting IFD have been worked out (table 2). By adopting the IFD approach a serious change in roles will occur. Table 3 briefly describes the effects of changing from a traditional approach towards IFD Building.

Figure 4. IFD Building organisation model

Table 2. IFD process outline

<table>
<thead>
<tr>
<th>Market research</th>
<th>Product development</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Market survey</td>
<td>• Performance specifications</td>
</tr>
<tr>
<td>• Client profiles</td>
<td>• Building morphology</td>
</tr>
<tr>
<td>• Product market combinations</td>
<td>• Product catalogue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Production facilities</td>
</tr>
<tr>
<td>• Production process</td>
</tr>
<tr>
<td>• Assembly and delivery</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PR &amp; promotion</td>
</tr>
<tr>
<td>• Sales facilities</td>
</tr>
<tr>
<td>• Client support process</td>
</tr>
</tbody>
</table>
Table 3. Changing roles IFD

<table>
<thead>
<tr>
<th>Party</th>
<th>Current role</th>
<th>IFD role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building user</td>
<td>passive</td>
<td>active</td>
</tr>
<tr>
<td>Architect</td>
<td>designer</td>
<td>industrial designer intermediary</td>
</tr>
<tr>
<td>Building contractor</td>
<td>builder/site manager</td>
<td>product development assembly</td>
</tr>
<tr>
<td>Government</td>
<td>project approval</td>
<td>system approval (by certification)</td>
</tr>
</tbody>
</table>

One of the basic principles driving the IFD comakership process is collaborative engineering. The development of building concepts demands multidisciplinary team efforts. Based on market information, defined in client profiles, these concepts will be worked out in detail. In order to reach an optimal product in terms of costs and productivity production and sales representatives will be actively involved. This will reduce the time to market of these products.

4.3 IFD product

Within this project an IFD building system has been developed. The basic structure consists of three parts: a core for services and transport, space modules and a shell (façade and roof). This structure applies for both dwellings and offices (figure 5 and 6). The development from the IFD system to a specific building is divided into three steps, for housing this is done accordingly. Firstly, several dwelling types, for specific client groups, are developed. These types have a predefined external volume. Secondly, within these types various layouts are worked out. Finally, these dwellings can be materialised and fitted out according to individual customer preferences.

Figure 5 and 6. IFD House (5), IFD office (6) (source, IAA/Ipostudio Architetti Ass., 2003)

An IFD building is: ‘a building, assembled from pre-designed building system components. The system is based on market research resulting in product market combinations (PMC’s). The PMC’s are matches between client profiles and building types. The building system consists of a mix of prefabricated components and –if preferred- locally available materials. From this system arises a limited range of solutions focussed on predefined client groups. An IFD building is flexible –now and in the future- its components are interchangeable, expandable and replaceable to meet future user needs. This prevents the building from becoming obsolete.’

5. IMPLEMENTING THE IFD CONCEPT

The results of IFD Buildings project will be presented in a workshop format, in order to support training and implementation of the concept. The workshop contains three parts: aim and motivation, the co-maker model and the roadmap to implementation. This outline consists of presentations, reports, tools and assignments. Part I introduces the concepts and supports the discussion on the need for IFD. Practical tools for marketing, design, development, production and sales of IFD Buildings are available in part II. Some of these results are worked out in an interactive format allowing people to get familiar with the IFD Building concept. On product level, as an example a practical building concept for both dwellings and offices has been elaborated. Scale models and VR presentations of these are available. Part III focuses on the definition of scenario’s for establishing IFD consortia.
The implementation of the IFD concept into the traditional construction industry is not simple. The initiative can rather be expected from the supply industry. However, a mere upscaling of their existing distribution channels will not be sufficient. A new IFD company will integrate new disciplines into their enterprises. This mainly concerns marketing and customer relations. Also methods for product development will have a more remarkable position. Expertise will be mobilized to integrate client information and product evaluation results in the improvement of the development of new products.

6. CONCLUDING REMARKS

While the Dutch IFD program has reached the final stage, IFD principles are not yet being widely adopted. By demanding higher quality building clients are increasingly compelling the industry to seek alternatives for their traditional, labour-intensive and rather inaccurate, construction technology. This is where Industrial, Flexible and Demountable building can contribute most advantages. The IFD program demonstrates the availability of innovative technology. But, as we have experienced once more in realising our new office building, the real bottleneck appears to be the organisation of the construction process.

The approach in the European IFD Buildings project represents a new business challenge towards producing and selling of buildings, introducing the concepts of co-makership and collaborative engineering (CE). These concepts respond to actual shortcomings in the construction industry and pave the way for the application of advanced technology in order to satisfy building clients. Implementing the concept of co-makership and CE will result in a significant breakthrough in construction industry. Moreover it will be a breakthrough for building end-users, who will experience an increase of building value for money.

7. REFERENCES

- Vos, Hans, van den Brand, Geert-Jan; Uitgangspunten van IFD Bouwen (IFD Building starting points), in: Bouwwereld, 1999
- European Commission, The competitiveness of the construction industry, 1997
- Van Gurchom, Hans; Netwerkanalyse IFD Bouwen (Network analysis IFD building), Master thesis in public administration, 2002
ABSTRACT: Research at the University of Southern California addresses a new construction automation approach using a layered fabrication process called Contour Crafting (CC). The process aims at automated construction of whole structures as well as sub-components. Using this process, a single house or a colony of houses, each with possibly a different design, may be automatically constructed in a single run. The basic Contour Crafting approach to construction, hereafter termed CCC (Construction by Contour Crafting), was presented in an earlier ISARC paper. This paper reports the new advancements in the CCC approach for integration of automated modules for tiling, for imbedding basic plumbing, electrical, and communication utility networks, and for automated painting.

KEYWORDS: automated reinforcement; automated tiling; automated painting; automated plumbing; automated electrical and communication network construction; Contour Crafting; mobile robotics

1. INTRODUCTION

Although automation has advanced in manufacturing, its growth in construction has been slow. With the exception of only a few successful attempts (see for example Balaguer et al., 2002) construction of whole structures remains largely as a manual practice. Conventional methods of manufacturing automation do not lend themselves to construction of large structures with internal features such as reinforcements, utility conduits, plumbing, electrical and communication line networks. This may explain the slow rate of growth in construction automation. A promising new automation approach is layered fabrication, generally known as solid free form fabrication or rapid prototyping, which uses an additive method and is capable of creating complex internal features. However, most current layered fabrication methods are limited by their ability to deliver a wide variety of materials applicable to construction. Additionally, they are severely constrained by the low rates of material deposition which makes them attractive only to the fabrication of small industrial parts. Currently Contour Crafting (CC) seems to be the only layer fabrication technology that is uniquely applicable to construction of large structures such as houses (Khoshnevis, 1998). In CC fabrication of layers with thickness of several centimeters is made possible by means of planar trowels which are positioned at the mouth of the material delivery nozzle the position and orientation of which is controlled by computer. An animation of the process may be viewed at the author’s web site (www.rcf.usc.edu/~khoshnev).

2. THE INTEGRATED CONSTRUCTION APPROACH

The proposed integrated approach to automated construction of whole buildings is based on CCC and includes the following components:

2.1 Automated fabrication of structures

Fabrication is performed by a new CC nozzle assembly similar to the one shown in Figure 1. This nozzle, which is being developed under our current NSF project, will be capable of co-extruding two different materials. The two side nozzles, each equipped with its own trowel, can deliver the materials that constitute the outside layer of walls, while the middle nozzle delivers the filler material which can provide structural strength. For example, the materials for outside surfaces may be plaster and
the filler material may be concrete. The tubes shown have an inner coaxial tube thereby allowing for co
delivery of two materials. The outside material may
be delivered first to provide a rim that contains the
filler material layer. To assure curing of the rims, the
filler material deposition may be one layer behind
the rim material deposition. Various approaches
such as thermal and chemical techniques may be
used to speed up the curing process. The middle
nozzle has slot to allow for imbedding of
reinforcements, as explained in the next section.
Using this nozzle design it is possible to create
openings within walls as utility conduits. A close-up
animation which shows the working of this nozzle is
also provided at the author’s web site.

2.2 Automated imbedding of steel reinforcement

Steel reinforcement may be built by creating two or
three dimensional steel mesh within walls and
columns using a progressive and layer-wise
approach. Three steel elements and two robotic end-
effectors will be needed as shown in Figure 2. For
walls, a two dimensional mesh may be built by first
imbedding the related vertical threaded elements at
equal distances and interconnecting them with the
horizontal “staple-like” element. The vertical
elements are screwed or attached by snap fits with
the layer below. The wall fabrication by CC then
continues as shown in Figure 1 and the process is
repeated for the next mesh layer. For columns, the associated vertical
reinforcement elements are placed at equal distances
on the lattice points of a two dimensional matrix.

2.3 Automated tiling of floors and walls

Automated tiling of floors and walls may be
integrated by robotically delivering and spreading
the material for adhesion of tiles to floors or walls,
as shown in Figure 3. Another robotic arm can then pick the tiles from a stack and accurately place them over the area treated with the adhesive material. These robotic arms may be installed on the same structure which moves the CC nozzle.

2.4 Automated plumbing

Because of its layer by layer fabrication method, a Contour Crafting based construction system has the potential to build utility conduits within walls. This makes automated construction of plumbing and electrical networks possible. For plumbing, after fabrication of several wall layers, a segment of copper (or other material) pipe is attached through the constructed conduit onto the lower segment already installed. The robotics system, shown on the upper left side of Figure 4, delivers the new pipe segment and in case of copper pipes has a heater element (shown in red) in the form of a ring. The inside (or outside) rim of each pipe segment is pretreated with a layer of solder. The heater ring heats the connection area, melts the solder, and once the alignment is made, bonds the two pipe segments. Other universal passive (requiring no active opening or closing) robotic gripper and heater mechanism designs used for various plumbing components are also shown in Figure 4. The needed components may be pre-arranged in a tray or magazine for easy pick up by the robotic assembly system. Using these components various plumbing networks may be automatically imbedded in the structure.

2.5 Automated electrical and communication line wiring

A modular approach similar to industrial bus-bars may be used for automating electrical and communication line wiring in the course of constructing the structure by Contour Crafting. The modules, as shown in Figure 5, have conductive segments for power and communication lines imbedded in electrically non-conductive materials such as a polymer, and connect modularly, much like the case of plumbing. All modules are capable of being robotically fed and connected. A simple robotics gripper can perform the task of grabbing the component from a delivery tray or magazine and connecting it to the specified component already installed. The automated construction system could properly position the outside access modules behind the corresponding openings on the walls, as specified by the plan. The only manual part of the process is inserting fixtures through wall openings.
into the automatically constructed network.

2.6 Automated painting

During or after layer-wise construction of walls a spray painting robotics manipulator, attached to the CC main structure may paint each wall according to desired specifications. The painting mechanism may be a spray nozzle, or an inkjet printer head (such as those used for printing large billboards). The latter mechanism makes painting wall paper or other desired patterns possible.

3.0 ROBOTICS APPROACHES

The original robotics approach proposed for Contour Crafting is depicted in Figure 6. This approach uses a gantry robot that has to be large enough to build an entire house within its operating envelope and lays one continuous bead for each layer. Such an approach is not without its attractions, but it requires a large amount of site preparation and a large robot structure.

An alternative robotics approach for CCC is the use of an inverted Stuart Platform system, such as the one developed at the US National Institute of Standards and Technology and named RoboCrane (see Figure 9). Application of RoboCrane in CCC is currently under study by researchers at NIST. In this project a concrete delivery system is devised and used in conjunction with a CC nozzle installed on the RoboCrane platform. Ease of transport and installation are the major advantages of this approach.

A third alternative robotics approach involves the coordinated action of multiple mobile robots. The mobile robotics approach depicted in Figure 7, has several advantages including ease of transportation.
and setup, the possibility of concurrent construction where multiple robots work on various sections of the structure to be constructed, the possibility of scalable deployment (in number) of equipment, and the possibility of construction of structures with unlimited footprint. In this arrangement various mobile robots performing various activities such as fabrication, plumbing, electrical work, etc. work in coordination.

A CCC Mobile Robot may use a conventional joint structure, as shown in Figure 8, and be equipped with material tanks as well as material delivery pump and pipes. The end effector of the robot could carry a CC nozzle that can reach from ground level all the way to the top of a wall. If the mobile robot arm could be made of a rigid structure, position sensing at the end effector may not be necessary. Instead, a position sensor (e.g., a laser tracker) may be mounted at a fixed location, and the related retroreflectors may be installed on each mobile robot base. In this configuration, the robot does not engage in fabrication while moving. Once it reaches a pre-defined post (called mobile platform post), it anchors itself by extending some solid rods from its bottom. Then it starts the fabrication from the last point fabricated while at the previous post. This arrangement is routinely practiced in some industrial applications such as robotic welding of large parts, such as in ship building.

Roof construction may or may not need support beams. Supportless structures such as domes and vaults may be built by all of the above robotics approaches. For planar roofs, beams may be used. Under each beam a thin panel may be attached to sustain the roof construction material delivered by the CC nozzle. In the mobile robotics approach the beams may be picked and positioned on the structure by two robots working collaboratively, each being positioned on the opposite sides outside of the structure. Delivery of roof material becomes challenging with mobile robots and may be done by a robot inside the structure. This robot may progressively deliver the material over the beam panels as each beam is placed on the roof. For the last few beams this robot could exit the structure and perform the material delivery from outside. An alternative approach for beam positioning and roof material delivery, which may be used in conjunction with the mobile robotics approach, is the use of the NIST RoboCrane system. RoboCrane may be installed on a conventional crane as shown in the lower part of Figure 9 (the top part of this figure shows the RoboCrane moving an actual steel beam.)

4. CONCLUSION

The CCC approach can provide for rapid and automated construction of near-complete structures that would only need door and window and various fixture installations. Due to its speed and its ability to use in-situ materials, CCC has the potential for immediate application in low income housing and emergency shelter construction. Construction of luxury structures with exotic architectural designs involving complex curves and other geometries, which are expensive to build using manual approach, is another candidate application domain for CCC. The environmental impact of CCC is also
noteworthy. According to various established statistics the construction industry accounts for a significant amount of various harmful emissions and construction activities generate an exorbitant amount of solid waste. Construction of a typical single-family home generates a waste stream of about 3 to 7 tons (City of Austin, 2002). In terms of resource consumption, more than 40% of all raw materials used globally are consumed in the construction industry (Lenssen and Roodman, 1995). Construction machines built for CCC may be fully electric and hence emission free. Because of its accurate additive fabrication approach Contour Crafting could result in little or no material waste. Estimates show that the CCC method will be capable of completing the construction of an entire house in a matter of few hours (e.g., less than two days for a 200 m² two story building) instead of several months, as commonly practiced. This speed of operation results in efficiency of construction logistics and management and hence favorably impacts the transportation system and environment.

There are numerous research tasks that need to be undertaken to bring the CC construction technology to commercial use. The activities reported in this article are the first few steps toward realization of actual full scale construction by Contour Crafting. Readers may obtain updated information on research progress at the author's web site.

5. ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation under Grants No. 9522982, 9615690, and 0230398, and by a grant from the Office of Naval Research.

6. REFERENCES


City of Austin Green Building Program (2002). www.ci.austin.tx.us/greenbuilder/


Demonstration projects "Industrial, Flexible and Demountable Building" in the Netherlands

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ABSTRACT: The programme "Demonstration projects Industrial, Flexible and Demountable Building" (known by its Dutch abbreviation IFD) is a joint initiative of the SEV with the Ministries of Economic Affairs (EZ), and of Housing, Spatial Planning and the Environment (VROM). The ministries are eager to promote the application of IFD building principles by industry and the market, so that the method can become embedded in conventional building practice. The motives of the ministries for participating in this programme are different. VROM has goals in the field of sustainability and durability, EZ hopes to improve the innovative force of the building industry. The SEV is the independent organisation that organises the selection of the projects, follows the progress in practice and disperses the lessons learned from the projects.

In this paper the following items will be discussed:
1. The IFD programme
2. IFD Building in the Netherlands
3. Background of the programme
4. The selection of new IFD demonstration projects
5. Lessons learned
6. What knowledge is missing?

1. THE IFD PROGRAMME

The IFD programme is being implemented by the SEV, in co-operation with the Foundation for Building Research, SBR. The programme will continue until the spring of 2005, during which time the SEV seeks to adopt demonstration projects through four tenders. The first acquisition of projects took place in the spring of 1999. From each tender, the best and most innovative projects were selected as demonstration project. The three project-tenders together yielded 71 demonstration projects. They serve to demonstrate innovative applications of IFD technologies, for both new constructions and renovation, public housing and utility building projects. The intention of the demonstration projects is to stimulate other parties to make use of IFD techniques. The use of IFD techniques might lead to a different way of organising a building project (Just-in Time delivery, after JIT-production of elements that are made under industrial conditions), new logistical solutions for flexible demands, reduction of (building) waste, better work conditions, and more profitable buildings. The most of these goals are not new, but already part of broader policy schemes of the Dutch government. Also, in the field of architecture, since the "Maison Domino" of Le Corbusier, there are discussions going on that are very much related to the topics of IFD building. MIT Professor John Habraken wrote a book in 1961 predicting the end of mass production in housing (habitants wanting more individual flexibility) that led to the founding of the SAR (Foundation for Architects Research) and later to the Open Bouwen group (Open Construction Methods). These initiatives yielded the terms "support" (structural elements, also called "casco") and "infill" (non bearing elements). The building industry did very little with these ideas, the emphasis lay on the building of as many dwellings as possible. And the Dutch building industry was very good at producing uniform dwellings with a good quality ay a low price. But, the market is changing, new answers are necessary.

2. IFD BUILDING IN THE NETHERLANDS

The principles of Industrial, Flexible and Demountable building are not new. For some time
now, innovative designers and suppliers have been active in developing new industrial concepts and products for the building industry, which could justifiably be included in the IFD category. The use of industrial building methods for offices, schools and factories has become more or less common practice. In circumstances leading to pressing demands for temporary accommodation, as the result of natural catastrophes or war, IFD construction methods have proved to be a natural choice because of the speed with which buildings can be erected and the fact that a uniform solution can be offered in response to tremendous volume requirements. The companies that are very strong in this market realise that the uniformity is not only an advantage, but in an open market also a disadvantage.

In the conventional building market, uniformity is a less valued factor; "modules" and "industrial products" are anathema to the companies and organisations commissioning building work. They want the building to reflect their own identity, not just to be one of many. A solution to this dilemma can be found in flexible product automation whereby standard basic modular products can be adapted to the customer's specific requirements and desires from project to project. That means that a standard building concept can be different in any location if some parts of the construction are flexible and demountable. That is possible with, for instance, industrial façade modules.

To date, however, developments seem to come to a halt after the one-off application of an IFD concept or product in a single project, and it has not proved possible to take the next step to products which are totally unrelated to a specific project. The construction world is not used to abstract innovations and new forms of cooperation. Compared to other industries, the building industry spends less than 2% of its annual turnover on R&D, and even then most of that investment can be attributed to the suppliers. The fragmented nature of the building sector, with many small businesses, and the way in which tendering is mainly concentrated on cost-based competition, provide little incentive for innovation.

In short, while there is plenty of interest in IFD building products and ideas from the supply side, there is not enough interest in the market, and IFD building principles are still far from being daily practice in the construction industry. In recent years, however, the users of buildings have become more outspoken, and the requirements and wishes they are now expressing display far more dynamism and variation than ever before. And especially in house building the emphasis is going more and more to private principals, who contract an architect who draws an unique dwelling for that principal. The Dutch government wants this way of house building for 30 % of a years building production of dwellings.

At the same time, the real estate market is changing from one, which is supply driven to one, which is driven by demand, and the principals are compelling their contractors to seek alternative solutions and seemingly unique buildings. And this is where Industrial, Flexible and Demountable building techniques can come into their own, in that they offer many advantages.

3. BACK-GROUND OF THE PROGRAMME

With this information in the back of their minds, Damen Consultants carried out an investigation in 1997 into the current market potential of IFD Building, and the possibilities for stimulating construction on the basis of this technology, on behalf of the Ministry of Economic Affairs (EZ) in 1997. The main conclusion to come from this investigation was that IFD building principles embody an integrated concept which can unite environmental and economic interests by offering creative solutions to the use of raw materials, fuels, labour, expertise and technology. Especially the environmental possibilities of industrial production methods versus old fashioned building methods, reductions of building waste, a more flexible use of existing buildings and dwellings, were for the Ministry of Housing a big incentive to participate in this programme.

4. THE SELECTION OF NEW IFD DEMONSTRATION PROJECTS

The SEV is seeking to highlight interesting projects, which demonstrate the innovative ways in which IFD construction methods can be put into practice. Construction principals such as project developers, corporations and municipal councils are invited to put forward projects for demonstration status. In addition, parties who only occasionally commission construction work are also invited to submit projects. The plans must be definite and apply to a specific location. One condition for applications is that the actual construction work may not have been started and no commitments may have been made with regard
to the components of the project, which are related to IFD construction principles. When assessing the projects the SEV will primarily consider criteria such as the degree of industrial production and co-operation which the project encompasses, the sustainability, innovative nature, and scope of application. The plans which best fulfil these criteria will be put forward by the SEV for the status of IFD construction demonstration project, together with the associated subsidy grants.

The SEV has set up an extensive expertise exchange network and information campaign around the projects which have been put forward for demonstration status. This campaign focuses not only on the demonstration projects themselves but also on the principles of IFD construction in general.

5. LESSONS LEARNED UNTIL NOW

Of those 71 selected projects until now, only 4 projects had to be stopped, for various reasons. June 2003, 27 projects are completed. When we analyse the demonstration projects, we see that half of the projects focus on Flexibility, about a third on Industrialisation and a fifth on Demountability. A fifth of the projects focus on all three aspects and as such contribute best to the integral concept of IFD.

Flexibility is in its nature the most important goal. Customers or building principals are interested in what to do with a building, rather than how to make it or how to get rid of it. This last item however deserves more attention and should become a point of concern. For cars or coffee machines we also pay some money in advance to make sure that at the end of the day, they can be properly taken apart and be recycled. For buildings this is not, or not yet, the case. 100% demountability is therefore only a strong item in temporary situations. We learn that in those circumstances “design for disassembly” usually means that parts of buildings must be disconnected. It helps when these parts are designed as products, instead of being put together on site out of (raw) materials. Some producers or builders call their building flexible in the sense of easy to remove; today a building, tomorrow an empty playfield. This is not the sort of flexibility we mean, this is pure demountable building.

Back to flexibility then, as main item for principals and those who help to establish the program of demands for a building. We speak of flexibility whenever a building is adaptable over time and over and over again in its volume and its lay-out. When only the first user or inhabitant can choose the lay-out and then the building is ‘frozen’, we call it freedom of choice. This should be otherwise a normal feature considering the amount of money involved in building your home or office building. A project with extensive possibilities of choice is complex in its logistics, but can be made with most traditional building techniques.

The real flexible projects learned us that a clear distinction in fixed and variable, or support and infill as you like, is most important. This distinction may vary in different situations. The expected type of use, the expected time span of use, the ownership, the physical context of the building (think about expanding) and also the context of building codes and regulations; all these aspects determine the level of flexibility one wants to reach in a program of demands. This asks of course for a rating of flexibility or a “flexindex”. We’re working on this item.

In the meantime the awareness of the specific need for flexibility is important. In some of our projects the intended level of flexibility was much higher than anyone would ever ask for in that situation. Even so the investments were higher and frustration is at hand. It’s a constant balance between predicting the future and today’s budget. Stewart Brand said “All buildings are predictions and all predictions are wrong.”

Technically we learned form all projects that a flexible building in the first place offers room for change, i.e. some over sizing of the casco. A great obstacle for change is of course the piping, ducting and sewage. In most IFD projects special products such as hollow floors and plug-and-play connectors were fitted in to make change possible. But especially for installation techniques, not all systems are already plug-and-play.

Industrialisation shows little progress, that is, on the scale of complete buildings. In most projects the steps that are taken are very small steps, and do not break with the standard techniques. Also the structure of the building industry is not affected, notwithstanding the problems with the logistics of how to get what a client wants from the drawing board into a real building or dwelling. Some other projects however are based on industrial concepts and have made a clear choice.
to do so. Typical for their approach is not necessarily the use of new and experimental techniques, but cooperation and coordination. The know-how of manufacturers and suppliers is brought into the design process in an early stage. This opens the door for simply good prepared work where improvisation and redesign are diminished. Mostly however, parties don’t want to come together this soon. A contractor wants to be free in choosing his materials and respective suppliers, because of economies. Where competition on price is the usual and only selling point, this approach asks for competition on quality and trust in cooperation. It also opens the door for innovations. Those partners who experienced a good team can work together on a library of building elements with which they can make several and different projects.

6. WHAT KNOWLEDGE IS STILL MISSING??

It might not be the knowledge that is missing, but the acceptance and implementation of it all that is the most important at this moment. Most principles described above, such as the distinction between fixed and variable elements, have been studied and proven to be profitable in theory. The building industry however has a conservative character and is divided in too many sub-subcontractors and advisors to profit from integral concepts. Introducing a new product usually means introducing a new step in the building process, also when this new steps replaces two or three former steps. The purchaser at a contractor’s office compares stand-alone materials and products instead of their contribution to the building (process) as a whole. There is not yet thinking in prefabricated elements. Bottlenecks in the building process, problems that occur every time and ask for re-work every time, are behind the planners desk sometimes simply denied. Costs of failure, or avoidable costs as they are better called, are somewhat like 10% of the total building costs. Some people then conclude that, knowing this is a vast figure, they can better use this “budget” on innovation, in every single project! That is a chance!

What knowledge for the ideal use of IFD concepts is still missing, and which proposals would we like to see in the last tender of IFD projects? Of course we look for real integral design and real integral flexible buildings.

There’s a lot of work to be done on installation techniques, to make installations adaptable and replaceable. On the side of logistic is a lot to learn, to avoid improvisation on the building site and to control the data-explosion generated by the many choices people can make while choosing their new home.

Important work is also to be done in different ways of calculating the exploitation of an IFD building, especially on the item of life expectancy of building materials and elements. Good insight in the cost of exploitation can convince a principal to invest a little more at the front. As said before, the principal is at the same time also in need of instruments like a ‘flex index’ to express and his demands.

Building regulations and planning procedures should facilitate flexible building and town planning.

We hope to learn more on these items, and in the meantime try to learn from foreign developments as well. The SEV will continue to support innovative and experimental ideas and publish about it, so others can use the lessons of IFD Building.
The factors of a successful industrial construction process

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1. INTRODUCTION

In the late ’80s and early ’90s, people at HBG Woningbouw came up with the idea of changing the way the construction of housing projects was organised in order to respond to the market demand for cheaper rented and owner-occupied accommodation.

They found that this project organisation could generally be characterised by the following aspects:

2. CHARACTERISTICS OF THE TRADITIONAL CONSTRUCTION PROCESS

1. Every new development is built up from scratch:
   Every new project development is built up from nothing and ultimately ends up with a set of specifications, contract drawings and a contract price for the work in question. The composition of the construction team that starts on this assignment changes for each project, as do the agreements concerning responsibility for the various aspects of the project. All members of the construction team are expected to do their level best on each occasion to ensure a definitive set of specifications and a final contract sum. In the process, each member of the construction team makes full use of the knowledge and experience he or she acquired on previous projects and tries to incorporate the successful experiences into the new project.

2. Choice of construction method is largely determined by the design:
   The choice of construction method is largely determined by the architect’s design and to a far lesser extent by the specific techniques that the contractor commands. As a result, contractors have all-round proficiency in many construction techniques, but lack specialisation in a particular construction technique, thus losing out on the efficiency benefits that such a specialisation could yield.

3. Projects are completed in varying team composition:
   Construction work is done by people. Each project requires a team of people appointed to carry it out. The composition of the team will vary from one project to another due to a project’s specific requirements and problems of co-ordination with other projects running at the same time. As a result, those involved make working agreements that only apply to that particular project. People obviously try and take the same agreements with them to subsequent projects, but these new projects have different teams and each member has his or her own working agreements to offer, and they once again have to reach some kind of compromise.

4. Projects are completed with varying subcontractors:
   Construction requires collaboration with subcontractors. Whatever applies to the agreements between project team members applies to an even greater extent to the agreements between the main contractor and subcontractor. These agreements often only become clear to both parties upon completion of the project. There is very little chance of being able to use the same agreements for a subsequent project, however, since the composition of the main contractor’s team will have changed and selection for a following project is often only based on the price involved.
The conclusion was that in the case of the traditional construction process, each project is considered to be unique, so that process improvements hardly extend beyond each individual project. Staff at the former HBG Woningbouw housing corporation for the north-west region of the Netherlands ultimately came up with the idea of changing the way in which the construction process is organised in order to keep the loss of know-how, experience and agreements to a minimum. This idea was put into effect in the early ’90s as the W&R-Bouwstroom construction flow; since then, more than 6,000 homes have been completed on the basis of the new concept. The idea was never intended as a means to develop a standard residential unit and build it wherever possible in the Netherlands, but rather to put up a large variation of units based on the idea of a standardised process.

Now, ten years on, we can say that the W&R-Bouwstroom concept represents a standardised process that can be used to construct a large variety of products, as you can see from the photographs below.

3. INDUSTRIAL CONSTRUCTION

The critical success factors for the process are as follows:
- Development and construction using a reference building
- Production using construction flows
- Co-making

3.1. Development and construction using a reference building:

The W&R construction flow has a reference home that is defined in a set of specifications, a set of working and detail drawings and a budget. The reference home is a complete residential unit that meets the requirements of current legislation and has a plain but effective finish. By using the reference home as a starting point, it is no longer necessary to start every development from scratch because a lot is already known when the development begins.

When a new development starts, the architect is commissioned to create a design based on the reference home. The architect is free to adapt the unit at his or her own discretion in terms of dimensions, extensions, rooftop structures and wall and roof finishes, provided these modifications can be completed using the standard process. The projects finished in the last ten years show that this has resulted in a large variety of home designs.

When the architect’s design is compared with the reference home, any deviations from the reference point can be identified relatively quickly and easily. The W&R organisation is completely familiar with the reference and it requires no further attention, so that the organisation’s full attention can be
focused on the deviations, from the first developments right up to the project’s completion. The price charged to the client is based on the reference home and includes a list of the deviations and their consequences for the price. This gives both client and architect plenty of time to identify relatively expensive or cheap plan deviations and take appropriate measures.

3.2. Production in construction flows

Each project carried out by the W&R organisation is scheduled into one of the 4 construction flows. A construction flow is the available production capacity; the organisation has to ensure that this production capacity is utilised to the full. This available production capacity comprises a project team, a production team and various co-makers. The project team and the production team consist of staff employed by the W&R organisation. Each construction flow project team has a fixed composition comprising a project manager, a co-ordinating foreman and 2 or 3 project organisers. Each construction flow has 4 production teams, i.e. a tunnel formwork team, a rooftop team, a wall/roof team and a joinery finishing team. All other activities required for the completion of the project are carried out by co-makers.

In addition to a fixed team, there is also a standardised production process. The total production process of a W&R project is split up into 42 subprocesses. For each subprocess, there is a description of the condition of the object when the responsible party starts work, what activities are required in that subprocess and the condition the object should be in when that part of the work is finished. These 42 subprocesses occur on every project. Essential subprocesses of the W&R process are:

- Piling work
- Prefab foundation beams
- Prefab rib-slabbed floor
- Frame with formwork tunnel cast on site
- Wall-sealing wooden frame construction elements
- Prefab roof structure

Since every project has the same subprocesses, it is possible to make far-reaching agreements with all parties regarding the efficient and effective execution of the subprocesses. Now that all parties are quite clear about what they are expected to do, we see in practice that parties point out any deviations from those agreements to the person responsible. Using this production capacity and the standardised production process, projects can be modelled on the reference home one after the other. The production process is always the same, but the location and actual product change from project to project. An activity on one project cannot begin until the same activity on the previous project has been completed. When projects are scheduled like this, under- or overstaffing is avoided and the available capacity is utilised as efficiently as possible.

Construction flow principle

![Diagram of construction flows]

The fact that the teams are always the same creates a situation in which the agreements made between the members of the team go beyond the project in question. This enables both the team and the organisation to progress to a higher level.
3.3. Co-making

The subprocesses that are not carried out by members of the organisation are performed in association with various co-makers, who assume responsibility for one or more subprocesses. An important reason for choosing co-makers is again that the agreements made between the main contractor and the subcontractor may go beyond the unique project, giving the process and the product an ever-improving price/quality ratio.

The co-makers are completely familiar with the reference home and each one has worked out what is required for his own subprocess on the basis of the reference. If a co-maker has ideas that can lead to optimisation of his process or product, he will notify the W&R organisation and the improvement can be incorporated into the annual update of the reference home.

Every year, a framework contract based on the reference home is concluded with the co-makers. Just as the W&R deducts the deviations from the reference home for its client, the co-maker indicates the deviations in each project in relation to his framework and a project assignment is drawn up. To make sure everybody involved is well aware of how the production process is progressing, a commencement meeting is held for each subprocess no later than on the starting date of each new project.

4. IMPLICATIONS OF AN INDUSTRIAL PROCESS

Continuous process improvement

By acting in strict accordance with these four success factors right from the very first projects, the existing four W&R construction flows have become a mobile factory with the conditions required for continuous process improvement, thus cutting the costs of failure. On each project, a progress meeting attended by the entire project team is held every four weeks. The ‘error cost list’ is a fixed item on the meeting agenda. This list is opened at the start of construction work and everything that goes wrong in the preparation or execution phase is put on the list along with the resulting failure costs. Keeping this list makes everyone aware of the consequences of the errors that are made and has a preventive effect for subsequent projects.

Splitting the process into 42 subprocesses with a clear-cut division of duties and responsibilities also has a positive influence on the reduction of failure costs. On the one hand, everyone is aware that any failure to fulfil agreements are pointed out to the party responsible. On the other hand, each respects the work of the other so that parties deal more consciously with the same failure situation. This prevents situations in which errors or shortcomings are concealed, only to be discovered at a later date or, worse still, after completion.

When the homes are handed over to the client, it is clear how the process progressed up to completion. In recent years, the W&R has managed to hand over homes with an average of no more than 4 flaws per unit in the hand-over report. Some projects have even been completed with an average of fewer than 1 flaw per home. These projects are characterised by easily manageable deviations from the reference, so the standardised process can be applied as efficiently as possible.

Changes for the client and the architect

When a client wishes to use the development and production facilities of a W&R construction flow, this will change a number of aspects of the traditional development and production process.

To make optimum use of the advantages, clients are best advised to decide whether they wish to utilise the W&R concept right at the start of a project. If a client opts for the W&R concept, it is important to hire an architect willing to design according to the preconditions laid down for the W&R reference home.
Examples of designs according the W+R concept
The client then commissions the architect in accordance with the Standard Conditions Legal Relationship Client Architect (SR) up to and including the Final Design (DO) phase and the procurement of planning permission. The client is advised to give the job of drawing up the structural specifications to BAM Engineering, because BAM Engineering is fully aware of W&R’s capabilities and they both know how the final documents should look. The same applies to the drafting of the structural working and detail drawings. The client is advised to call in BAM Engineering for the same reasons.

In close consultation with all parties concerned, the construction team then drafts the design for the specific project. Using the architect’s initial sketches, the W&R can provide a quick indication of the consequences for the construction costs. Once the architect has completed the Final Design (DO) phase and a price has been agreed between the client and BAM Woningbouw, BAM Engineering starts with the draft of the working and detail drawings, also referred to as product specification. The client and architect are always best advised to wait until completion of the product specification and use these documents as a basis for the planning permission application and presentation documents. This procedure, which is shown in the diagram below, prevents a great deal of checking work for all parties concerned and makes it difficult if not impossible for any discrepancies to occur in these documents, because the product specification is worked out to the last detail.

![Diagram: Design [by Architect] → Working drawings [by Engineering]

- Application drawings
- Presentation drawings
- Product specification
- Contract drawings

- application drawings = working drawings +/- too much + what’s missing
- presentation drawings = working drawings +/- too much + what’s missing
- product specification = working drawings +/- other documents
- contract documents = working drawings + invoice [+ specifications]

- responsible for planning application: Architect
- responsible for the sale: Vastgoed
- responsible for the working drawings: W&R
- responsible for the contract: Vastgoed & Regio

Before starting work, a good construction team will always draw up a Preparatory Activity Schedule (abbreviated to VAS in Dutch) containing important milestones in the timeline. An important milestone for the W&R-Bouwstroom is the planned commencement of construction in relation to the required continuity of the 4 construction flows. Solid agreements concerning changes in the VAS are made during the development of the project. Once BAM Woningbouw have been awarded the contract, the W&R organisation can make a definitive decision on which construction flow the project in question is to be allocated to.

In comparison to traditional projects, once construction work begins, nothing much changes for the client and architect other than that they are now dealing with a seasoned team that can build the homes according to a schedule agreed on in advance. If the process runs smoothly, the homes will be delivered to satisfied buyers with a minimum number of flaws in the hand-over report.
Automated Project Performance Control (APPC) of construction resources

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ABSTRACT: Real-time control of on-site construction is a growing field still in its infancy. A model for automated control was developed, implemented and validated in the field, to verify if Project Performance Indicators (PPI) can be automatically measured and controlled. The concept behind this development is that indirect data – locations measured automatically at regular time intervals – can be collected automatically and converted into PPI using computerized algorithms. The model was implemented in a concept-proving prototype for productivity measurement. The prototype was tested in four construction projects – three buildings, and one road – to validate the concept and test the feasibility of developing a full-scale prototype. The encouraging results of the field experiments confirmed that it is possible to convert the locations, automatically measured at regular time intervals, into productivity, and thus automatically control them. The expected accuracy of such a system is ±10-20% for building construction and ± 4-5% in road construction.

KEYWORDS: Automated Data Collection; Control; Manpower; Monitoring; Performance Measurement

1. INTRODUCTION

Real-time control of on-site construction, based on high quality data, is essential to identify discrepancies between desired and actual performances. Such control enables timely corrective measures to be taken when needed and, consequently, a reduction in damages caused by the discrepancies. The longer it takes to identify discrepancies, the more serious the potential damage is and the more complex and costly the corrective measures will be.

The performance is measured in terms of project performance indicators (PPI), such as cost, schedule, quality, labor productivity, materials consumption or waste, etc. The role of the control system is to identify the discrepancies – the construction manager then identifies the causes for the deviations and, accordingly, decides about appropriate corrective measures. Accurate data is needed not only to control current projects, but also to update the historic database. Such updates enable better planning of future projects in terms of costs, schedules, labor allocation, etc.

Project engineers and managers, involved in construction, spend a disproportionate amount of time collecting and processing construction data, typically causing the construction manager to be distracted from the more important task of supervising and controlling the project [McCullouch]. Because current data collection methods are expensive and time consuming, many construction companies do not collect detailed data and even less in real-time. Consequently current methods do not enable corrective measures to be taken in time to mitigate the damage to the ongoing project. Corrective measures can be effective in the ongoing project if they are taken in real time, or shortly after the deviation occurs. Sometimes project managers and/or foremen do perform some control on-site, but this is normally not done in a systematic way and may be done at long time intervals. Consequently, decision-making may sometimes be based on intuition.

The construction industry is changing – projects are becoming more complex and sophisticated. Consequently, controlling them is becoming more difficult, but at the same
time, more needed. Data collection technologies, enabling faster and more accurate data acquisition, are beginning to be used by the industry. Many efforts and achievements have been made to model construction projects, enabling the integration of computerized design and construction functions. Additionally, automated data collection techniques have emerged, which can be used for real-time data collection [Ciesielski]. The declining cost of hardware allows the use of automated data collection (ADC) technologies in real-time control systems.

2. PROJECT PERFORMANCE CONTROL

Project performance control can be defined as the identification of deviations between the desired and the actual performance of a project. The problem with this definition is that it is difficult to determine the desired values for project performance indicators. This is due to the diverse nature of construction projects where even ‘identical’ projects are normally built under different conditions.

A comparison between the desired and the actual performances is the beginning of the control procedure. When a deviation is detected, the construction management analyzes the reasons for it – the deviation can be schematically divided into two groups: (a) unrealistic target setting (i.e. planning), or (b) causes originating from the actual construction. (In many cases the causes for deviation originate from both sources.) If the deviation is caused by the actual construction, the construction manager analyzes the reasons for it and takes corrective measures that will bring the actual performance as close as possible to the desired one. Consequently, the definition of the desired performance is very important. Normally the tendency is to equate the desired performance with the planned one because it increases predictability and reduces uncertainty.

When the deviation is caused by unrealistic target setting (plans), the latter and the historical database have to be updated. This approach, where initially the desired performance is the planned one but as the project progresses, after analyzing the actual performance, the desired performance changes accordingly is called Adaptive Control.

Effective control needs two types of information in real-time: (a) a list of the activities to be performed on the given day, broken down in terms of PPI. (b) Measurement of the actual performance in the same terms. The first type of information is automatically extracted from the Project Model – PM [Sacks et al.], which has up-to-date project planning and design data. The best way to measure the actual performance in real-time economically is by automating it.

3. AUTOMATED PROJECT PERFORMANCE CONTROL

The main challenge today in automating the control process is the automated measurement of the performance indicators. There are many examples of measuring devices, which evaluate a given parameter indirectly, e.g. analogue thermometers, which actually measure changes in volume and translate them to temperatures; scales, which measure displacements and transform them into weights; Global Positioning Systems (GPS), which measure time-of-flight of a signal from known reference stations and calculate positions. The same approach is used here for automated PPI measurement – the values of some indirect parameters are measured automatically and converted into the sought value of the PPI by special algorithms.

3.1 Conceptual Framework

The basic concept behind the selection of the indirect parameter is the fact that to construct a building, a road, or any other facility, the ‘construction agent’ – worker or equipment – has to be close to the constructed elements. Therefore, knowing the construction agent’s location at a given time, together with additional information (automatically extracted from the PM), the activity, in which the construction agent is engaged, can be determined. Consequently, it is possible to determine what the construction agent is doing at all times by automatically measuring its locations at regular time intervals. A variety of technologies can measure locations (e.g. GPS),
and others can be developed on the strength of off-the-shelf technologies (e.g. Radio-Frequency based measuring techniques).

3.2 Principles

A control model determines what a construction agent is engaged in at the time the location is measured. The model associates the measured locations to a construction activity, or activities, on the strength of their vicinity to the construction elements correlated to the activity. This process will be explained for a case study of wall painting (Fig. 1).

A work envelope (WE) is defined to assist with the association of locations to construction elements: it is a volume in space where a construction agent, working on an element, could be located. The shape and type of a WE depends on the nature of the activity, the type of element and the construction technology. For example, the WE of the wall painting, depicted in Fig. 1, is a prism of approximately the wall’s planar measurements with a width, which is determined by the technology. Thus, if a measured location is enclosed within the WE, it is associated with the appropriate activity. In the present example, location 1 is associated with painting wall ‘A’, and 2 with wall ‘B’. This process is called Geometrical Association (GA).

Locations number 3 and 4 are more difficult to associate, because location 3 is enclosed within two WE and location 4 is not enclosed within any. Such locations are associated, at a second stage, by an algorithm called Logical Association. The latter uses decision rules, which are based on work continuity, on crew affiliation, or on statistical considerations.

3.3 Concept Proving

The idea was examined in two stages: (a) checking the basic concept – i.e. that the activity a construction agent is performing can be determined knowing its location. (b) Applying this concept to control earthmoving equipment in road construction.

Simulated field experiments carried out for the first stage, in three building construction sites, verified the concept. In each of these experiments c. 10 activities were checked by simulating location measurement at regular time intervals. The measured locations were fed into a computerized algorithm that determined which activity the workers were engaged in, for each measuring cycle. A comparison with what the workers actually did (determined by parallel manual measurement) confirmed the concept. The accuracy level of the simulated measurement was ± 10-20% – a detailed report is given in [Navon 2003a].

The model was realized in a prototype system, to control earthmoving equipment in road construction, and tested for three weeks in a road construction site. The productivity of four activities was measured with the system and, at the same time, it was recorded manually so that the accuracy of the model could be assessed. A GPS was mounted on each of the pieces of equipment performing the controlled activities. At the end of a working day, the data recorded by the location measurement system was post processed and transferred to the prototype system for productivity calculations. The latter was compared to the calculations based on the data collected manually.

The comparison between the output of the prototype and what was actually performed indicates that an accuracy level of ± 4-5% can be expected in automated control of earthmoving operations – a detailed report is given in [Navon 2003b].
4. CONCLUSION

Traditional project performance control is usually generic (e. g. cost control techniques). It depends on manual data collection, which means that it is done at low frequency (normally once a month) and quite some time after the controlled event occurred (i.e. not in real-time). Moreover, manual data collection normally gives low quality data and is error prone.

Automated Project Performance Control is a novel approach, still in its infancy. It shows real potential to provide effective control of construction projects, thus solving an acute problem in construction management.

5. REFERENCES


The Development of a Robot for Paving Floors with Ceramic Tiles

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ABSTRACT: In 1997 a development project was started aiming on mechanisation of the process of paving floors with ceramic tiles. Together with a number of companies from The Netherlands, Germany and Belgium and with additional funding from the European Commission the project was carried out by A+ innovations in co-operation with the Eindhoven University of Technology, Department of Architecture, Building and Planning. The development was based on an analysis of the traditional tiling process and includes a range of devices for several stages of the tiling process.
This paper includes a short overview of the total development. More particular it focuses on the core development: the tiling robot. Several concepts are discussed. This holds for the robot device but also for the carriage, the software and the control. A special aspect was the necessity of ‘forward tiling’. As a consequence the robot has to move over the tiles that have been laid just a minute ago. It is evident that this approach is critical for the mortar bed. Also the development of a mortar bed was part of the development.
Finally conclusions are drawn:
Apart from the deliverables of the project, which implies a.o. a working robot also conclusions have been drawn regarding the main success factors.
• The development is based on a market problem;
• The development is structured by experience with product development;
• The market (tiler) was involved in the development, especially during the definition phase and in testing situations;
• The commitment and drive of the participants

KEYWORDS: Automation, Ceramic tiles, Development, Robot, Success factors.

1. INTRODUCTION
On basis of market needs a development project was set up in order to achieve a degree of automation and robotizing in the field of paving floors with ceramic tiles. The project was funded by a number of companies and the European Community under the industrial & Materials Technologies Programme (Brite-EuRam III). The development was carried out by A+ innovations in co-operation with the Eindhoven University of Technology, Department of Architecture, Building and Planning and a key contribution of Kranendonk Production Systems and Hilhorst Tegelwerken.
This paper presents the present achievements of the development, as well as the status quo and future developments.

2. TRADITIONAL TILING MARKET
Floor covering with ceramic tiles has been applied since about 3,000 years before Christ. Naturally an evolution took place for the ceramic tile as well as for the mortar bed and the processing. The present market however is changing so much that in fact one can regard the traditional paving technology as out of date:
• the technology is labour intensive;
• the market for tile floors is under pressure by the high prices, a.o. because of the dependency of labour;
• tile floors are ousted from the market by floor coverings from a minor quality, which affects the quality of building;
• labour circumstances for the tiler are very bad (about 10% of the tilers is disabled before they are 52 years old);
because of the bad labour circumstances the attraction of the tiler-profession is decreasing and the problem of finding professional tilers is increasing.

For the above mentioned reasons it is obvious that structural changes have to take place to supply the market in the future with tile floors, as no alternative exists for tiles with the same performance.

Analysing the labour in tiling activities the work can be divided into three main activities:

a. Spreading and levelling the mortar;
b. Placing the tiles;
c. Finishing (levelling, tightening, joint filling).

Figure 1. Tiling labour

It is obvious, that this development is also very important for the future of the ceramic industry. All over Europe tiling is a very well accepted technology and tiled pavements are beyond any alternative. Europe is a typical ceramic area (world leader). Countries like Italy, Spain and Portugal do have a strongly developed ceramic industry, which is still very prominent all over the world. Also countries like Germany, France, UK and The Netherlands have industries with an international reputation.

The total production of ceramic tiles in the European Community is about 780 million m² (which is more than 50% of the total output in the world. From this production about 21% is exported, whilst about (strongly increasing) 13.5 million m² (= about 2%) is imported.

Yet the industry is threatened by a strong competition from countries outside Europe, the market for ceramic pavements is under pressure, not only by the negative health-reputation of the tilers, but also by the decreasing competition possibilities in comparison to pavements from countries with low wages like Brazil, Taiwan and China and other materials for floor covering (coatings, PVC, laminates, et cetera).

The participants in the project were interested to extend the applications of new technologies in view of better working circumstances and better competition possibilities. This on a co-operative basis with the tile industry and the machine builders.

3. DEVELOPMENT PROGRAMME

The development programme was aiming at a total solution for the tiling profession and consisted of work packages.

WP 1 Preparatory arrangements.

In this work package an analysis was made of the tiling practice and the requirements in different building projects, especially the projects suitable for automation. These are mainly projects with large surfaces such as railway stations, commercial buildings, garages, industrial buildings, warehouses, etc.

Especially requirements concerning the strength, the flatness, the slope, the integration of gutters, flexible joints, studs, etc. ware subjects of this analysis.

WP 2 Development of a device to transport and rule the mortar bed

The work in this work package originally concentrated on modifying an existing machine of Drion Constructie BVBA for on site producing of concrete cycle-paths.

Under pressure of WP 3 however it was decided to focus on the tiling robot and postpone the development of this device.

Nevertheless the work in this work package regarding the development of a suitable mortar bed was quite essential for the success of WP 3. As can be seen hereafter de design was based on a device moving on top of the floor shortly after being placed. This was considered to be a very critical factor for the quality of the mortar bed. The University Eindhoven performed a research programme in order to develop a suitable mortar bed.

As a spin off in the frame of this WP a device to rule and level the mortar bed was developed and adapted.

WP 3 Development of an expedient to pick and place tiles

In the frame of this WP it was foreseen, that possible adaptations of tiles had to be realised. These adaptations refer mainly to control the tolerances of ceramic tiles.

The main part of this work package however was the pick and place device, which during the development process was developed as a robot. (see here under).
WP 4  Finishing device
This work package was focussing on the development of a vibrating plate in order to compress the mortar bed, to suture the tiles and to level the floor. This device was developed as a stand alone tool.

Robot
This paper focus on the development of the tiling Robot. WP 3 however was originally not aiming on a robot design. The first conceptual design for a device for picking and placing tiles was based on a hand controlled device. This device should have been able to pick up about 1 m² of tiles in one movement. However manipulating with this weight turned out to be difficult. It should be kept in mind, that the pallets with tiles had to be carefully prepared in the right pattern and no disturbance could be allowed.

Another problem was, that the device had to be installed on a fork-lift truck. Due to the weight this concept was to work according to the withdrawing principle and therefore to drive over the unfinished floor. This was causing inaccuracy but also a logistical problem, since the mortar bed had to be realised in-between.

These problems prevented the possibility of a substantial reduction of labour.

On the moment that it was clear, that the device had to move over the tiled surface and a special carriage had to be developed it became attractive to reconsider the total concept.

After about one year of development the first two designs for a robot based concept were made.

On the carriage there is also space for a limited stock of tiles. An additional satellite shuttle carriage will provide the robot with sufficient tiles.

On the back of the carriage also the power unit has been installed.

The device can be semi hand controlled or completely be automated. Finally the project is aiming at a sensor controlled configuration. By laser technology the robot holds contact with reference points installed in the hall in order to continuously calibrating the position of the robot.

Part of the concept is also a preparation station with a robot that will be able to sort tiles and to prepare pallets with certain patterns of tiles. In the preparation station also the satellite shuttles will be supplied.

This part of the concept is not developed yet. Meanwhile Röben Tonbaustoffe GmbH is prepared to supply the tiles pre-sorted on suitable pallets.

Critical factors in the development were the software development in relation to the necessary accuracy and velocity and the development of the carriage.

For the carriage for example, three prototypes were developed.

4. RESULTS

After a development period of about five years most of the aimed developments are established.

- A device for ruling and levelling the mortar bed;
- A device for tightening the mortar bed, to suture the tiles and to level the floor;
- A mortar design which is characterized by a high stability short after producing;
- An improvement of the accuracy of industrial tiles was established;
- A suitable method for palletising and transporting tiles was developed;
- The tiling robot was developed.

Apart from the deliverables of this project, the author was also interested in the project as a case study in the frame of an analysis of success and failure agents in product development.

The main success factors in this project are:

- The development is based on a market problem;
The development is structured by experience with product development;

The market (tiler) was involved in the development, especially during the definition phase and in testing situations;

The commitment and drive of the participants;

The original purpose was to develop a robot exclusively for the Hilhorst company. Meanwhile plans have been made to bring the concept to the market as a product. Under the name IKASK the product will probably be introduced in 2004.

By a market introduction in view, the development again is accelerating right now. In the next year the sensor control and the satellite shuttle will be developed. The development of the preparation robot will follow short after introduction. Especially this development and the market introduction approach will depend on the availability of venture capital and partners and agents for other market areas.

The benefits for the participants are that they will maintain their existing market and extend this and that they will enlarge their working area by cost savings per m² (competition possibilities). By mechanisation of the labour and the cohesive costs, participants will have the possibility of extending their working area and also improve the quality and lighten the working circumstances.

In the working area an extra potential market of at least more than 1 million m² can be achieved. With a share of 10% this means an extra turnover of about € 3,500,000.- every year for the SME participants.

For the ceramic industry it is to be expected that they will enlarge their market with at least 20-30% (150-200 million m²; turnover € 3,000-4,000 x 10⁶). The increase can be achieved by new special products that are suitable for export and that can compete with other floor coverings.

6. CONCLUSIONS

Apart from the deliverables of the project as been discussed, some conclusions can be drawn regarding the success factors in the development process.

- The development is based on a market problem;
- The development is structured by experience with product development;
- The market (tiler) was involved in the development, especially during the definition phase and in testing situations;
- The commitment and drive of the participants;

7. REFERENCES

Lichtenberg, J., Segers, S., 2000, Mechanisation of Ceramic Tiling, End report EC Contract no BRST-CT98-5238, Project no: BES2-2676
A Multi-element System of Surrounding Recognition And Objects' Localization for Unmanned Ground Vehicles

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ABSTRACT: Equipping engineering machines and trajectory vehicles with automatic and remote control systems is necessary in case there is any environmental hazard for an operator i.e. environment conditions, an impact from fire field etc. It is particularly crucial when there is no possibility for any person to be in a machine or in its close surrounding. It applies to both extreme environment conditions (high temperature, pressure or environment contamination) and the likeliness of direct man health and life hazard (i.e. removal, disposal or neutralization of hazardous materials or area demining – particularly when the enemy operates on a fire field). In all above cases of using engineering machines and trajectory vehicles there is a need to remote control without the possibility of using direct impulse feedback by operators. That is the reason why it is so necessary to work on elaboration vision system enabling determination of the machine location in geodesic system and operating accessories configuration.

This paper describes an overall characteristics of the steering unit in an unmanned ground vehicle depending on tasks to be performed, considering the drive and the steering’s system structure required. Current development of visual systems used in unmanned ground vehicles has been shown. A visual system to be used in remote controlled machines and ground vehicles has been presented. Its structure and limitations within picture depth estimation resulting from the system’s structure have been presented. Furthermore the system of defining the cameras’ location in an external reference system has been described.


1. INTRODUCTION

The intense development of industrial robots used to perform jobs of possible hazard to humans was the activator of efforts towards developing Unmanned Ground Vehicles (UGV). Many opposing technological and environmental factors, significantly reducing the possibility and social-economical efficiency of robotizing numerous processes in terms of production were not taken into consideration in comparison with range conditions – the necessity of performing constantly alternating tasks at lack of surrounding recognition, together with an interfering or even destructive environment influence [3,4].

Focusing exclusively on the problems of controlling the operation of UGV, it has to be said that the steering system structure depends highly on the kind of tasks to be performed – what is unmistakably shown in fig.1. Within UGV development for the needs of the broadly understood military sphere as well as security and technical rescue, seven main types may be distinguished (fig. 1) – differing from one another not only with the assignment but also with the way of power generation and steering.

The presented scheme clearly shows fundamental differences among various UGV resulting from the drive type and steering system structure required. In opposition to the steering system of a typical working machine or vehicle, the unit featured in the scheme shows the problems resulting from remote control. Carrying the operator away makes it necessary to add additional information channels through which the data could flow (data of the run of a working process), and above all, it forces adding data channels for broadcasting the view of the surrounding or operation field of a mobile working machine.

The basic assumption in industrial robots’ operation is accomplishing the route of an element, put in motion as a result of combination of the movements of the robots kinematics segments in a collision-free
Transport of dangerous and harmful materials in hazardous conditions inaccessible to mobile robots and manipulators.

Breaching the engineering obstacles on the battlefield in extremely hazardous conditions.

Remote control vehicles with breaching devices for removal and neutralization of dangerous materials (e.g., mines, artillery shells, missiles) and others (e.g., to weaken effects of military operations or natural disasters).

Remote control vehicles for neutralization of dangerous (lethal) blowing charges (e.g., mines).

Removal and neutralization of dangerous materials (lethal).

Reduction in terrorist hazards and effects of natural disasters

Observation and supervision of objects (e.g., buildings, nuclear power plants, pipelines) inside different objects (e.g., buildings, nuclear power plants, pipelines).

Remote control of different materials and objects in hazardous conditions inaccessible to mobile robots.

Earth-moving processes and reloading of materials and objects in hazardous conditions.

Transport of dangerous and harmful materials on the battlefield.

Passive observation and surveillance of the battlefield remotely arranged/deployed devices for observation and surveillance.

Elimination of terrorists and enemy in fighting.

Control and surveillance of operation remote or autonomous control with developed systems of surroundings analysis and decision processes.

Remote control in teleoperator system with main elements located out of board.

Remote control with developed systems of recognition.

Remote control in teleoperator system with main elements located on board.
operating area. As for UGVs, the basic issue is to recognize the environment it is in, localize terrain obstacles and moving along a track optimally close to the one assumed according to the criteria given. It implies the following requirements and limitations referring to the steering system structure and the surrounding recognition system:
- elimination of direct impulse feedbacks between the vehicle and the operator forces
- expansion of information generating and transmitting systems for the operator as well as supporting the process of generating signals steering the energetic track of the vehicle;
- developing emergency procedures for the steering system operation in case of interferences occurring in transmission and providing the autonomy of the vehicle’s operation within such conditions;
- generating stimuli for the operator, which nature and range of information given are close to the ones received in the operator’s cabin.
- development of the measuring-diagnostic block which will broadcast control signals to the operator’s stand, working autonomously

The above mentioned requirements and limitations were the basis for developing - throughout the research studies till now – a scheme of a functional system of remote control of UGV (fig.2) [1,5]. Efforts towards developing such vehicles are undertaken in numerous countries but their broad scale implementation in armed forces, technical rescue and anti-terrorist actions is still not the fact.

The key issue in realizing the project is to develop an effective system of recognizing the vehicle’s surrounding – capable of detecting and localizing obstacles and other objects of possible hazard to it or being un crossable.

Localization methods have been developed for years. They may be divided into several groups. The first one bases on detecting translocation in relation to artificial active markers (eg. light, ultrasonic) or passive ones. This approach most often uses triangulation [9]. GPS is also a similar method but its accuracy however is not sufficient enough for autonomous navigation.

An other method of localization is determining the vehicle’s position in virtue of vector or raster maps [7]. In this method, the data obtained by the sensors is compared to the one stored as a map which gives the possibility to determine localization and orientation. The basic disadvantage of the methods mentioned above is the fact that an area map or the exact localization of the markers are needed in order to use these methods.

There are numerous methods of creating a map of the surrounding of a mobile vehicle and stating its localization. However the task of creating a map and stating translocation „on-line“ has not found satisfactory solution so far. It mainly results from the fact that in order to create a map, precise location must be known beforehand. As for stating translocation basing on sensors indications, it requires knowledge about a map or location of artificial and natural markers, i.e. knowledge about the surrounding.

There are separate modules for composing a vector or raster map in classical navigation systems and a topological map in the more advanced systems. There are many methods of localization but the one that is used most often is odometry due to being cost effective [2]. It enables exact determination of translocations in case the vehicle’s movement time is relatively short and sudden changes of velocity and direction resulting from wheels and caterpillars slipping do not take place. The main disadvantage of odometry is that inaccuracies hard to calculate cumulate in time. It is caused by systematic errors e.g. uneven wheels, limited resolution of decoders and accidental errors e.g. differences in wheels' slip resulting from loads, uneven surface.

In methods being developed recently no assumptions about the environment are made – the vehicle finds characteristic surrounding features and determines its location itself on the basis of camera data and determines its translocation towards chosen markers. The chosen object should possess features that do not depend on the robot’s location. The vehicle’s choice is strictly related to the kind of sensors it is equipped with. In case of a robot observing the surrounding with a camera, it should be an object of unique colour or shape and in case of active sensors the markers may also be walls, corners or doors. Processing camera view and building surrounding’s map upon it is most often time consuming and requires significant calculation powers.

2. SURROUNDING RECOGNITION SYSTEM FOR UGV

Standard visual systems perceive reality in a two dimensional way (because of no possibility of measuring distances to the objects and their sizes). Therefore, the main research problem in visual systems is the three dimensional perception of picture, especially depth. Data
about the spatial location of objects that is not included in a single picture is included in e.g. stereoscopic picture.

Therefore, a significant problem is to develop the most advantageous configuration of a visual system in consideration of signals' processing speed and the information quality required.

Figure 2. Functional scheme of the remote control system of unmanned ground vehicle

That is why it is planned to couple a visual system with a system of laser telemeters. The methods of creating „surrounding view” will be an evolution of classical algorithms of creating raster and topological maps. Considering the fact that the information about the obstacles’ and vehicle’s location will be coming from a number of sources, methods of information aggregation will be used. Use of diffusible algorithms enriched with reflexive systems' elements is assumed for planning the vehicle’s path [8].

At the initial stage of the research, a standard stereo-visual system was assumed. A visual system consists of two main blocks: the operator’s stand and observational system was built in the Machine Construction Institute of the Military University of Technology for that purpose (fig. 3).

The observational system consists of a steering head (1) with a carrying beam fixed onto it (2). Change of the beam’s rotation degree is realized by the steering head. A GPS device put on the beam in the head’s rotation axis reeds the azimuth and specifies: the unit’s location in geographical coordinates, altitude above sea level and ground incline. The GPS data may be put onto a digital map – which enables to draught e.g. the vehicle’s route (with a visual system installed). The observational system is also used to observe the terrain or chosen objects with CCD cameras (6), which orientation is set by the heads (5). The system’s structure enables the observation of chosen objects by the two cameras simultaneously (realizing stereo-vision process) or observation of objects located in different directions (azimuths).

Figure 3. Research observational system (description included in the text)

The described visual system may be used as well for localizing the observed object and its surrounding observation along with detecting terrain obstacles but also for observation and visualization of the location of working equipment of engineer’s machines. It may be mounted on a vehicle, or an engineer’s machine as well as independently fitted outdoors and used for geodesic localizing of stationary and moving objects [6]. The further research stages are supposed to deal with using telemeters for detecting and localizing obstacles and objects.

A laser telemeter delivers a series of measurements of \{\varphi_i,d_i\} nature, where \(d_i\) – is the distance to the obstacle given by the sensor at scanning angle \(\varphi_i\). In case of laser telemeter manufactured by SICK the resolution of scanning angle equals 0.5°, and scanning range is 180°. The telemeter conducts 20 full measurements within a second, with 1cm accuracy. The maximum range of the device is 100 m. The coordinates of the obstacle may be calculated with the telemeters indications with the equation (1) (fig 4):

\[
\begin{align*}
x_i &= x_R + d_i \cos(\varphi_i + \varphi_R) \\
y_i &= y_R + d_i \sin(\varphi_i + \varphi_R)
\end{align*}
\] (1)
where \(d\) is the distance to obstacle indicated by laser and \(\phi_i\) is the scanning angle, the threesome \((x_R, y_R, \phi_R)\) – specify the location and orientation of the vehicle in the reference system assumed. The indications of a laser distance sensor may be also treated as a picture. A pixel of \((x, y)\) coordinates has a non-zero value if in the area corresponding with \((x, y)\) a fragment of an obstacle will be detected. As an example, laser telemeter’s data for obstacles map shown in figure 5 is shown in figure 6. Spaces where obstacles have been detected were marked with black dots.

An acceptable translocation direction is the one for which the measure’s of obstacles’ occurrence value does not exceed the threshold given. Basing on data analysis (from fig. 7) the histogram featured in fig. 8 was created. The directions in which the vehicle is able to move are the ones that has the obstacles’ occurrence value lower that the assumed threshold. The sectors where the vehicle should not appear are marked grey in the figure 7. Laser telemeter’s data enables not only to specify safe directions of vehicle’s movement but also to determine vehicle’s translocation between the measurement points given. Hough’s transformation was applied in order to determine vehicle’s changes. It makes parametrical specification of obstacles’ shape possible. Monitoring changes of these parameters we may specify orientation change and translocation of the vehicle [2,3].

The suggested system may be used to avoid collisions [1]. The method of avoiding collisions is based on an algorithm of directional histograms. In this approach the robot’s surrounding is divided into identical sectors, a measure of obstacle’s occurrence is calculated for each of them, then a histogram is made and its values are threshold. The direction of robot’s movement is acceptable if the measure of obstacles’ occurrence lies below the threshold given.

\[
m_{ij} = a - bd_{ij} \quad (2)
\]

where: \(a, b\) – vehicle dimensions related parameters \(d_{ij}\) – distance between vehicle’s centre and the obstacle

\[
h_k = \sum m_{ij} \quad (3)
\]

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Laser telemeter’s data enables not only to specify safe directions of vehicle’s movement but also to determine vehicle’s translocation between the measurement points given. Hough’s transformation was applied in order to determine vehicle’s changes. It makes parametrical specification of obstacles’ shape possible. Monitoring changes of these parameters we may specify orientation change and translocation of the vehicle [2,3].
3. CONCLUSIONS

Specifically operating conditions of a multi-purpose astronomical vehicle make full duplication of solutions already in use in mobile robots impossible. The analysis featured suggests that individual approach to the issue of design of the steering structure of such vehicles, depending on their technological tasks is necessary. The main problem conditioning realization of the steering system shown i.e. developing a system for visualizing the vehicle’s surrounding was indicated.

The system’s main task is to generate information about objects’ location, their translocation in case of remote control – in a hardly or unrecognised environment. The research visual system shown in the paper may be used as well for localizing the observed object along with observing its surrounding and detecting terrain obstacles.

Coupling a system of laser telemeters into it may provide an effective system of detecting and localizing mobile objects as well as obstacles in UGV’s operating area.

4. REFERENCES

Research of the Snaking Phenomenon to Improve Directional Stability of Remote Controlled Articulated Wheel Tool-Carrier

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ABSTRACT: Articulated wheel tool-carriers manufactured up to 20-25 tons of total weights are wide available on the construction equipment market and have a lot of unique advantages not accessible on Ackerman steering or truck-mounted equipment such as:
- for weight up to 20 t high cross-country mobility – comparable to heavy military tracked vehicles due to size of wheels;
- excellent manoeuvrability and keeping attachment straight ahead during turning;
- high lift capacity due to heavy axis construction;
- high pulling force;
- wide range of tools and attachments due to quick-coupling device;
- high productivity;
- high reliability and durability.

Moreover their steering systems and transmission are easy to automation due to hydraulic control systems. For those reasons they could be useful and cost effective on hazardous areas and robotised construction sites.

There is one unsolved problem, which limits the speed of operation and efficiency of using – they have poor directional stability. During straight movement the articulated tractor deviates from straight line and permanent driver correction is required. The path has oscillation shape so it is called snaking phenomenon. So in the case of remote control the speed is limited to 5-6 km/h. The higher road speed above 30 km/h of driver controlled tractor need an operator aid system that would improve directional stability of articulated tractor too. Designing such system demand perfect knowledge of snaking phenomenon arise reasons.

This paper describes tests and trials conducted on 20 tons articulated wheel loader to get answer how the snaking phenomenon is arisen. Used methods, achieved original results and their analysis are presented. It could be basis for future works on articulated tractor directional stabilisation system.

KEYWORDS: articulated tractor, high speed, identification, remote control, snaking phenomenon, steering system

1. INTRODUCTION

In Ackerman steering system thanks the geometry of suspension the stabilising force and moment appear. The steering play lets them acts independent, without the driver attention. This feature has not gets articulated steering system and snaking phenomenon always appears. It is illustrated in fig.1. It shows the travel path of articulated tractor, which is oscillating round the theoretical direction of movement. Lack of directional stability of movement caused by too high speed or too low skill and experience of driver gives growing deviation and finally the machinery is leaving road strip (permitted corridor of movement).

In order to determine all main reason of arising and growing the snaking phenomenon the experimental research was conducted. As the test object was used the loader SL -34 -weight 19,5 t and net engine power 162 kW (manufactured by Huta Stalowa Wola) in two versions of steering system, offered by manufacturer:
Type 1 – with mechanical feedback and gain $w = 1/5.5$ - applied in machines first generation;
Type 2 – with hydraulic feedback and gain $w = 1/3.2$ – operating in L-S system with
priority valve and amplifier - applied at present by almost all manufacturers of construction machines, and 2 research systems designed by authors:
Type 3 - direct working with hydraulic feedback and gain \( w = 1/6.5 \) - without L-S system and amplifier;
Type 4 - direct working with hydraulic feedback and gain \( w = 1/16.2 \) - without L-S system and amplifier.
As a gain “\( w \)” in steering system the inverse of number of steering wheel turns needed to realizing the full turn of frame was called.
After introduction tests [Lopatka] it was affirmed that in all steering systems the oscillations has similar period of vibration – about 2.5-3 s. From the type of steering system is depending only the value of maximum deviation amplitude and driver effort measured as angle of steering wheel revolve.
To eliminate claims that snaking phenomenon is some kind of natural frequencies or that arise because of excising the critical speed – this values was identified.
As a next step the research of steering system acting was conducted and finally the influence of driver on machinery stability was determined.

To find them the simple test was conducted. The steering system was excited with fast steering wheel revolve and the recorded pressure in cylinder shows the oscillation with natural frequency of system. The results (fig.2) shows that period of vibration is 0.4 s and the frequency is 2.5 Hz. Compared to period 3 s of snaking phenomenon it is clear that they are not connected and snaking phenomenon is not kind of vibration related with natural frequency of steering system.

2. THE NATURAL FREQUENCY

The steering system of articulated tractor always contains 1 (in small equipment) or 2 hydraulic cylinders and moved with them 2 masses connected to front and rear part of articulated frame. The oil in the cylinder gives the spring and damping effect. So, such system always has gets natural frequencies.

3. THE CRITICAL SPEED

The critical speed characterize the vehicle mass distribution and lateral tire stiffness. During straight movement any disrupt due to different front and rear tire deformations changing him in some kind of circular movement and centrifugal force is appeared. The value of this force depends on the speed. When the centrifugal force is greater then stabilizing forces from tire stiffness the vehicle is not stable - leaving the strip and driver steering corrections is needed. The maximum value of speed when the vehicle is stable is called critical speed.
Conducted test shows (fig.1) that tractor is loosing his stability with speed not exceed 28 km/h. Executed mathematical calculations indicated value of critical speed equal 44 km/h but credibility value can be find only in empirical way. To obtain this, the test according to [SAE] was performed. We decided for method 4 – constant speed/variable steer angle test and conducted them at a rate of 28 km/h. How to use the test results to determine the critical speed is demonstrated in fig.3.

According to assumed guidelines, during tests were recorded:
- the change of steering wheel turn angle $\beta$;
- the lateral acceleration $a_p$ in the cab.

On the basis recorded dates the directional control response characteristics were plotted – fig.4. It show that the tractor not achieved the critical speed and it is much more higher then developed 28 km/h.

Moreover it indicates that from critical speed point of view the loader at speed 28 km/h is stable and has got understeer characteristics. So, one may say that snaking phenomenon is not related to critical speed of vehicle.

4. THE STEERING SYSTEM OPERATION

Changing of movement direction and steering of articulated equipment is realized by turns of articulated frame with hydraulic cylinders of steering system. Each turn is related with pressure and flow changing. To know how it operates and what phenomena takes part during steering such signals as:
- pressure in both cylinder chambers;
- steering wheel angle;
- turns of articulated frame or
- length of steering cylinders;

should be measured.

In first steep the resistance of steering was determined. As a measure of resistance the pressure difference between active and passive cylinder chamber was used.

Example of recorded signals during steering on firm surface is shown in fig.5. It indicated that after steering the system is not stable. In active chamber of cylinder after steering the pressure is higher then in passive chamber about 0,8 MPa and it correspond to the steering resistance moment equal 4 kNm. This is a residual steering moment and it appears because of oil compression in active chamber of cylinder. This moment is trying continuing the steering process but the resistance is too high. The value of this moment is depending on steering resistance and velocity of frame turning.

Figure 5. The steering wheel angle and pressure during steering on hard surface – loader is stand still

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Figure 6. The pressure in both active and passive chambers of steering cylinders during tractor movements
When the tractor is moving the steering resistance is lowering and this residual steering moment is caused the turn of articulated frame up to time when the pressure in both chambers are equal fig.6. In these times the length of active cylinder is growing about 1-1.5 mm – fig.7. It correspond the turns of articulated frame about $\Delta \beta = 2.7^\circ$. To compensate it the driver must makes revolves of steering wheel on about 9 deg. If he do not do it the tractor would achieve the permissible deviation $\Delta y_{\text{max}} = 0.35$ m according to [ISO], after 22 m.

Figure 7. The changing of steering cylinder length as results of residual steering moment acting

Figure 8. The forces in steering cylinders calculated from the pressure

The pressure measure permitted to determine forces in both – left and right cylinders – acting on articulated frame – fig.8. It shows that the frame is continually stretched – each cylinder develop the mean force about 5 kN amplitude oscillation is about 2-3 kN. This mean that joint is stretched by force about 10 kN and in this steering system has not gets any plays.

5. THE SNAKING PHENOMENON GAIN REASONS

For comparison of working efficiency of studied steering system arrangements, the time delay between signal from sensor of hydraulic steering cylinder length and signal from sensor of steering wheel turn angle was used. Analysing obtained results (fig.9,10) it is possible to affirm, that in standard arrangement the time delay is equal $\Delta t \approx 0.45$ s and it is higher then in arrangement with L-S system, where the delay is kept on level $\Delta t \approx 0.35$ s. One should pay attention that in L-S type arrangement although the signal time delay is decreased, the snaking phenomenon is more intensive and vehicle can loss their stability of movement (fig.1). This is due to considerably larger gain of steering system improving manoeuvrability and raising work efficiency during typical tasks as well as lowering the number of turns of steering wheel indispensable for realization of working cycle and the same the operator's effort.

Figure 9. Time delay between steering wheel angle and cylinder length – steering system – Type 1
Figure 10. Time delay between steering wheel angle and cylinder length – steering system – Type 2

The growth of gain in steering system as well as growth of signal delay is the main causes of increasing the snaking phenomenon. However, in essential, its scale depends on operator's skill and predisposition.

In order to recognize the possibility of snaking phenomenon limitation by means of gain limit as well as signal delays, two direct working research systems were designed - Type 3 and Type 4.

As a result of L-S arrangement elimination, the transmission time and delay was shortened in designed steering systems up to $\Delta t = 0.05\,\text{s}$.

Table 1.

<table>
<thead>
<tr>
<th>Steering system</th>
<th>Gain in steering system</th>
<th>Signal time delay</th>
<th>Average deviation amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>1/5.5</td>
<td>0.45 s</td>
<td>27.4 cm</td>
</tr>
<tr>
<td>Type 2</td>
<td>1/3.2</td>
<td>0.35 s</td>
<td>58.4 cm</td>
</tr>
<tr>
<td>Type 3</td>
<td>1/6.5</td>
<td>0.05 s</td>
<td>18.0 cm</td>
</tr>
<tr>
<td>Type 4</td>
<td>1/16.25</td>
<td>0.05 s</td>
<td>8.1 cm</td>
</tr>
</tbody>
</table>

Although the signal time delay in steering system was considerable decrease (tab.1), the snaking phenomenon was limited in considerably smaller range. It should be taken in consideration that the smallest deviations from theoretical track, appear in arrangement with the smallest gain. On this bases the conclusion can be made that the operator is one of sources triggering the snaking phenomenon – limitation of possibility of his influences by gain decrease - stabilize the movement of machine, and the growth of steering system gain led to losing of stability and leaving the traffic lane.

This is completely in agreement with car research results described in [Chaczaturow] as driver behaviour. When the driver is highly concentrated because of narrow corridor of travel – his reaction period is equal about 2.5-3 s.

So, in this way the main snaking phenomenon frequency is a driver excitation frequency. At this high speed of tractor movement it is a maximum velocity of driver reaction on sensed deviations.

6. DEVIATION SENSING DELAY

Because of sensed by driver lateral deviations limits their reaction and stability of movement, the research to determine possibility of improvements this sensing was conducted. In this order three position markers were situated on machine and the motion path was recorded with the digital video camera.

Two markers (A and C) were intended to marking the motion paths of the front and rear of machine (located in distance 2.5 m from joint), and third (B) – showed the operator inclination – it was fixed in axis of the joint (fig.11). They possess measuring mesh which make up white and black squares side length 5 cm, arranged in figure “chessboard”. Both the pattern and the size of elements were well-chosen on the ground of earlier conducted tests – their goal was achievement maximum legibility as well as possible to obtainment measuring accuracy, depended from resolution of recording system.
The position and distance of recording camera were carefully chosen too, in order to assure the indispensable sharpness in whole measuring range.

The analysis of registered courses of motion paths obtained with video recording method (fig.12) shows, that the rear part of machine in relation to the front gets about 30% larger values of maximum side deviations. It results mainly from lower stiffness of rear axis tires working with almost 2-times lower inflation pressure than in front one.

The character of registered courses is completely consistent but it should be noted that deviation sensed by operator (marker B) is delayed about 0.5 s in comparison with the movement of front of machine (marker C).

This delay explains why the hydraulic system improvements – 9-times reducing delay in steering system – are limiting deviation only 3-times. Time delay in sensing of deviation is comparable to delay in commercial steering systems.

Dislocation the driver's seat (or future remote control sensors) from current position (close to frame joint) to the front of tractor - can be essential to accelerate the operator's reactions and to improve the stability of articulated machine movement.

7. INITIAL TURNS OF FRAME

Because in articulated tractor the driver fulfil the controller function it is necessary to determine his accuracy of operation. For this reason the simple test was conducted. After starting of movement the operator should adjust the frame in straight position and this angle of frame turning was measured to obtain error of adjustment. Example of test results is demonstrated in fig.13.

![Figure 12 Recorded articulated loader markers movement paths](image)

Figure 13. Initial turns of articulated frame – the driver mistake

It shows that the frame always has initial turn angle because of driver mistakes – error depends of his skill and experience and can reach 1 deg. This initial frame angle causes quick leaving the traffic lane and necessity driver acting.

8. CONCLUSIONS

Conducted at MUT research shows that main reasons of arising the snacking phenomenon are:

- residual steering moment and
- initial turns of articulated frame.

This phenomenon is gained by:

- time delay in hydraulic steering system – it is depend on established technical solution;
- time delay in deviation sensing – it is depend on dislocation of driver or remote control sensor/indicator;
- high gain in hydraulic steering system;
- low experience of driver.

The most important conclusion is that in articulated tractors the stabilising function of steering system is fulfilled by driver – however effects of his efforts are depend on signal time delay and gain used in arrangement, and sensed stimulus. Taking this in consideration the stabilising systems – aided the driver is possible to design and limitations of deviations and snaking phenomenon during remote control operation can be achieved.

9. ACKNOWLEDGEMENTS

The authors like to thank Polish Ministry of Science and Informatisation (Grant no.T00345346) for the financial support.
9. REFERENCES


Automatic Control of road Construction Machinery – Feasibility and Requirements

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ABSTRACT: A wide range of construction machines are used in the course of road building. Automation offers a number of benefits and improvements to the control of the work processes. A total of 16 different work procedures involving 13 construction machines were evaluated using the measurement criteria developed for this purpose. Total points scored by the procedures varied from 8 for 15 (maximum being 22, minimum -11, the average 11.4, and standard deviation 2.0). Only one of the work procedures evaluated in the course of study was found to be unsuitable for automation. The criteria were developed to highlight the essential features and details required for further automation in road construction.

KEYWORDS: automation, road construction, heavy machinery, feasibility evaluation, measurement criteria

1. INTRODUCTION

This paper evaluates the applicability of automation to the control of road construction machines in Finland. The aim of the study was to discuss the feasibility of the automation of the most commonly used road construction work procedures and machines and related requirements. A general field study was carried out to enable the feasibility study.

A total of eleven indicators were developed to evaluate earlier experiments with the automation of road construction machines. The feasibility of automation for each work procedure was assessed using these criteria. The machine control system of a motor grader was used as a frame of reference for the evaluation of other machines. The functional idea of these instruments was to emphasise essential specifics that are regarded as fundamental for considering automation for road construction methods. The following criteria were used for the feasibility evaluation:

1. Does the work procedure include any repetitive task?
2. Is it possible to mechanise the work procedure or has it already been mechanised?
3. Is there any potential for minimising material losses?
4. Does automation improve the overall efficiency of the work procedure?
5. Are the requirements for geometric accuracy essential in the work procedure?
6. Is the design data required for machine control available?
7. How technically complicated is the implementation of automatic control?
8. Does the work procedure involve any tasks that are dangerous or hazardous to human health?
9. Does automation improve the competitiveness of the contractor?
10. Does automation improve the standard of quality of road structures?
11. Does automation in road construction promote sustainable development and improve the state of the environment?

2. MATERIALS AND METHODS

2.1 Measurement criteria

A total of eleven (11) indicators or criteria were developed in the course of the present study to allow an objective identification and evaluation of the potential for automation in road construction. Naturally, these indicators do not cover all the aspects and prerequisites for automation. However, it was established that these eleven
indicators give a fairly extensive presentation of the factors illustrating the importance of automation in road construction. The main purpose of the indicators developed in the course of the evaluation of the potential for automation was to identify and highlight the individual factors affecting automation. At the same time, the results of the measurements made and their comparison are likely to offer some guidelines for further research and product development. The indicators were:

1. **Does the work procedure include any repetitive task?**
   This indicator is based on the idea that the greater the number of individual, identical, repetitive "standardizable" tasks that a specific work procedure includes, the easier it is to automate it. Conversely, a lower number of such identical tasks means that automation is difficult.

2. **Is it possible to mechanise the work procedure or has it already been mechanised?**
   One of the prerequisites for automating any work procedure is its potential for mechanisation. What this indicator seeks to illustrate is the degree to which machines are employed to perform the work, i.e., the mechanisation rate. The greater the percentage of mechanised work, the greater the scope for automation. Improvements to the machinery may also be called for. In terms of mechanisation, individual machines may require modifications before automation can be applied on a larger scale.

3. **Is there any potential for minimising material losses?**
   If loss of materials can be reduced or the required operation carried out using less material, financial gains may be made by improving the work procedure. In road construction, any savings that can be made in the materials used for the structural layers are highly significant. The potential for savings is determined by the price of the material - the higher the price, the greater the savings potential. Another possible source of substantial savings is the consumption of binders (such as bitumen, cement, etc.).

4. **Does automation improve the overall efficiency of the work procedure?**
   This indicator is used to evaluate the work procedure as a whole. If the construction machine is the bottleneck in the process or serves as the basis for evaluating the required work input, automatic control will affect the entire process directly. Therefore the potential for automation is quantifiable. If, by contrast, the bottleneck lies somewhere else, the overall efficiency of a work procedure is not much improved by the automation of a single work operation, meaning that any benefits gained thereby are slight.

5. **Are the requirements for geometric accuracy essential in the work procedure?**
   Accuracy requirements (tolerances) are often the underlying reason for efforts to increase automation. If these requirements are high, accurate measurements and control may be justifiable. More often than not, it is difficult for human beings to achieve the required accuracy with conventional work procedures. However, if the accuracy requirements are secondary, it is hard to identify any major potential for automatic control. As far as actual road construction is concerned, the required level of accuracy can be determined from things such as whether any levelling labels/rods are required on the site for alignment. As a rule, height accuracy requirements for roads are stringent (sometimes calling for absolute and sometimes for relative accuracy).

6. **Is the design data required for machine control available?**
   Numeric machine control requires a model for such control. This indicator helps to evaluate whether the current design process generates the geometric and other data required for machine control. The data can also be obtained on site before or during the actual work operation. If such data is currently unavailable, the overall procedure needs to be developed in this respect as well in order to apply automation. If, by contrast, the data is available, it will facilitate the development and introduction of automatic control. If the design data is available easily or at low cost, automation will require less effort. Other important considerations in this respect include issues such as whether CAD is used for the design of the component or work operations, whether the data is available in electronic format and whether the design has been carried out in a 3D environment.
7. **How technically complicated is the implementation of automatic control?**

If automation requires extremely complicated technology, it is difficult, though possible, to gain financial benefits from automating the work procedure. This indicator is used to evaluate the need of 3-D control of machine, the level of competence required to control the machine (operator skills, number of "human sensors", precision control), feasibility of 3-D positioning, functionality requirements, number of sensors required on the construction machine, popularity and reliability of the required control logic, number and/or level of latent uncertainties, operator's expectations as to benefits and other similar factors.

8. **Does the work procedure involve any tasks that are dangerous or hazardous to human health?**

One of the driving forces in automation is the desire to improve safety at work. This indicator is used to evaluate the number of dangerous operations (accident statistics, accidents resulting in injury or death). For example, deep excavations can be dangerous while machines, as such, may pose a risk to people. Other considerations related to this indicator include the level of "hardship" in work (harmful effects of impurities, – alveolar air, skin, clothing, etc.), amount of hard and enervating work (worn-out joints, overexertion, etc.), occupational safety aspects of machine manoeuvring techniques and workplace ergonomics as a whole.

9. **Does automation improve the competitiveness of the contractor?**

It is unlikely that automatic machine control systems will be introduced on a large scale unless they are financially profitable to contractors. This indicator is used to evaluate issues such as whether automation reduces the required work input (the greater the reduction, the greater the potential for automation), added efficiency provided by automation, level of required capital outlays (primarily the purchase price of automatic control technology relative to the purchase price of the standard construction machine and assumed increase in efficiency), the hourly rate and/or unit price paid to the contractor (if the price is low, the investment in automatic control does not pay off), whether it is a question of a strategic investment (no contracts awarded in the absence of automatic control systems), whether automation will replace some other work operation (such as automatic quality control measurements), whether the procurement policies and types of contract permit the purchase and operation of machines with automatic control, and the financial benefit of the investment to the contractor (benefit/cost, payback period).

10. **Does automation improve the standard of quality of road structures?**

One of the basic reasons for introducing automatic control is to improve the standard of quality or to meet the applicable quality requirements. In road construction, the main quality criteria include the immediate improvement in geometric accuracy as well as reduced segregation, improved compaction of the structural layers, reduced susceptibility to frost action, improved strength, reduced settling, extended service life and reduced need for maintenance.

11. **Does automation in road construction promote sustainable development and improve the state of the environment?**

Research on the environmental impact of road construction is expanding. However, there is little data on actual findings. For the purposes of this study, the "eco-indicator" is used to focus general attention on how automation affects the environmental impact of various work procedures and/or to what extent recycling is increased because of automation. If automation reduces energy consumption (because of the reduced harmful impact of the generation/use/transmission of energy) or decreases the need for transporting materials (in road renovation projects materials are ground and mixed on site without any need for transportation), this may be considered as offering added potential for automation in terms of the environment.

### 2.2 Field study

A straightforward method of evaluation was devised to carry out the field measurements:

1. **Identification of the work procedure**

The first step is to identify the most common working operations and procedures used on road construction sites (Sections 2.1-2.2), i.e., what it is that is done and how. Several different procedures may be used to achieve the same final result.
A description of the work procedure must be provided at least to the level of accuracy dictated by the indicators used for determining the potential for automation (Sections 2.1-2.2). Essential issues and factors include the following:

- method of input measurements and planning, tools
- construction machines and manual work procedures involved, percentage of human labour
- requirements for 3-D control of machines and blades, required operator skills, current problems
- materials to be used
- accuracy requirements (tolerances)
- work operations that are potentially dangerous or hazardous to human health
- price of machinery, contractor’s profit margin, level of compensation to contractor
- effects of the work procedure on the quality of road structures, sensitivity, i.e., the level of impact
- environmental impact of the work procedure, environmental performance.

3. Measuring the potential for automation

The potential for automation is gauged using the indicators developed for the purposes of the present study (a special form for recording the results of field measurements is provided).

Scoring:
2 points if the presence of the property being measured is strong or exceptionally clear in the work procedure;
1 point if the presence of the property being measured is perceptible in the work procedure;
0 point no presence of the property being measured is discerned in the work procedure;
-1 point if there is a negative presence of the property being measured, i.e., an opposite negative effect is exceptionally strong.

4. Processing of the results of the measurements

Each work procedure is analysed specifically to each indicator and accompanied by a verbal description. The total points scored for each work procedure are added up. The greater the number of points scored, the greater the potential for automation.

Scale:
15-22 points the work procedure is highly suitable for automation which offers great potential for financial benefit
9-14 points the work procedure is suitable for automation which offers clear potential for financial benefit
3-8 points the working method is not that suitable for automation which offers little potential for financial benefit
-9…+2 points the work procedure is poorly suited for automation which offers no foreseeable financial benefit.

3. RESULTS

The scoring results of the examples grader, milling machine and excavator are presented in the tables 1-3.

When the superstructure of a road is built, the laying and shaping of the sub-base and load-bearing layer is usually carried out with a grader. The chain of work operations include a number of clearly identifiable tasks such as preparations, spreading and shaping of the material forward, reversing with the blade up, and finishing. Preparations and finishing also include relocation of the machinery. Essential in the operation of a grader is the correct adjustment of the spreader and shaper blade to match the geometry of the road. The number of measurements and adjustments required is very high. At the same time, the accuracy tolerances are tight down to ±20 mm in the vertical direction (load-bearing layer). With the 3D positioning technology and an automatic 3D model, it is possible to achieve a level of accuracy and efficiency that is beyond non-automatic systems. The potential for savings in terms of the required work input is great. A grader is used side-by-side with other road-construction machines, so that a successful sequence of machine operations is essential to the quality of the road structures. Graders are also used for winter maintenance which includes a number of specific tasks in which efficiency could be improved through automation.
The stabilising work operations designed to improve the structure of the road include preparations, initial planing, shaping of the layer and, if necessary, the addition of aggregate, stabilisation milling, and finishing. Stabilisation with bitumen (foam and emulsions) is the most common method of structural road improvement used on "low-grade" roads in Finland. However, further research is called for if a technically and financially sound automated stabilisation milling is to be achieved. Operations that could be automated included milling depth, angle of gradient, infeed of binder, infeed of additive (water). Final shaping and levelling is carried out with a grader even in stabilising milling.

Figure 1. Road grader – the reference.

The standard work operations included in excavation include preparations, intake of material in the bucket, turning and dropping the load, and finishing. The most common method is that of using the back hoe excavator. Controlling the position of the machine and all the 3-D control tasks calls for great expertise on the part of the operator. For example, maintaining the stability of the machine requires close control and adjustment. For an inexperienced operator, the work can be risky, even dangerous. In embankment filling operations, the excavator is used to shape and finish the structural layers and slope ramps in three dimensions. The angle through which the machines turns should be as narrow as possible. In cutting and embankment-filling operations, the requirements for geometric accuracy usually range from ±5 to ±10 cm and may be even greater for finishing. Thus, 3D control may be indispensable in finishing operations.

Figure 2. Milling machine – manufactured in Finland.

Figure 3. Excavator.
Table 4. Results of measurements to determine the potential for automation.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>truck</td>
<td>9</td>
</tr>
<tr>
<td>wheel loader - loading</td>
<td>8</td>
</tr>
<tr>
<td>wheel loader - finishing</td>
<td>13</td>
</tr>
<tr>
<td>caterpillar</td>
<td>12</td>
</tr>
<tr>
<td>road grader</td>
<td>14</td>
</tr>
<tr>
<td>gravel spreader</td>
<td>10</td>
</tr>
<tr>
<td>roller - compaction of unboued layer</td>
<td>12</td>
</tr>
<tr>
<td>roller - compation of bound layer</td>
<td>10</td>
</tr>
<tr>
<td>milling machine</td>
<td>10</td>
</tr>
<tr>
<td>excavator - cutting and embankment filling</td>
<td>10</td>
</tr>
<tr>
<td>excavator - finishing</td>
<td>13</td>
</tr>
<tr>
<td>pile driver</td>
<td>14</td>
</tr>
<tr>
<td>in-depth stabiliser</td>
<td>12</td>
</tr>
<tr>
<td>bulk stabiliser</td>
<td>10</td>
</tr>
<tr>
<td>rock auger</td>
<td>11</td>
</tr>
<tr>
<td>asphalt spreader</td>
<td>15</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

The results of the evaluation of the potential for automation of road construction machines using the indicators developed in the course of the study are presented in Table 14 as numeric values. This approach makes it possible to assess automation potential systematically. The method is described in this report and may be used for prioritising future product development projects. If the grader analysed in this project is used as a frame of reference (see the observations and results obtained in field testing), a general evaluation of the potential for automation of other work procedures and construction machines can be made using this approach. The total number of points scored by the grader was 14.0, slightly higher than the average for all machines which was 11. (standard deviation being 2.0). Assuming that the indicators cover all the contributing factors extensively enough, it is safe to say that financial benefits correlate with the results of the measurements. Consequently, indisputable financial benefits may also be expected from the automation of other work procedures. However, the present study is probably not extensive enough to provide any unambiguous proof of the benefits of automation.

5. REFERENCES


Table 1. Analysis example: the results of measurements for a road grader.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Many</th>
<th>Some</th>
<th>None</th>
<th>Neg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Does the work procedure include any repetitive task?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2. Is it possible to mechanise the work procedure or has it already been mechanised?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3. Is there any potential for minimising material losses?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4. Does automation improve the overall efficiency of the work procedure?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5. Are the requirements for geometric accuracy essential in the work procedure?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6. Is the design data required for machine control available?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7. How technically complicated is the implementation of automatic control?</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>8. Does the work procedure involve any tasks that are dangerous or hazardous to human health</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>9. Does automation improve the competitiveness of the contractor?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>10. Does automation improve the standard of quality of road structures?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>11. Does automation in road construction promote sustainable development and improve the state of the environment?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

points 10 5 0 -1

total points 14

Table 2. Analysis example: the results of measurements for a milling machine.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Many</th>
<th>Some</th>
<th>None</th>
<th>Neg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Does the work procedure include any repetitive task?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2. Is it possible to mechanise the work procedure or has it already been mechanised?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3. Is there any potential for minimising material losses?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4. Does automation improve the overall efficiency of the work procedure?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>5. Are the requirements for geometric accuracy essential in the work procedure?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6. Is the design data required for machine control available?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7. How technically complicated is the implementation of automatic control?</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>8. Does the work procedure involve any tasks that are dangerous or hazardous to human health</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>9. Does automation improve the competitiveness of the contractor?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>10. Does automation improve the standard of quality of road structures?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>11. Does automation in road construction promote sustainable development and improve the state of the environment?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

points 6 5 0 -1

total points 10
Table 3. Analysis example: the results of measurements for an excavator.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Many</th>
<th>Some</th>
<th>None</th>
<th>Neg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Does the work procedure include any repetitive task?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2. Is it possible to mechanise the work procedure or has it already</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>been mechanised?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Is there any potential for minimising material losses?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4. Does automation improve the overall efficiency of the work procedure?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5. Are the requirements for geometric accuracy essential in the work</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>procedure?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Is the design data required for machine control available?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7. How technically complicated is the implementation of automatic control?</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>8. Does the work procedure involve any tasks that are dangerous or</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>hazardous to human health?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Does automation improve the competitiveness of the contractor?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>10. Does automation improve the standard of quality of road structures?</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>11. Does automation in road construction promote sustainable development</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>and improve the state of the environment?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

points  6  5  0 -1

total points  10
Procedure Design for Experiments Towards Modeling of the Cutting Force in Excavation of Bulk Media

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Ferri.hassani@mcgill.ca

ABSTRACT: The work discussed in this paper concerns automation of excavation or automation of loading particulate media by an excavating machine. Based on the analysis of the process, knowledge of the force of cutting/digging is required for feedback purposes. The lack of a reliable and well established model for the force in question dictates the primary work of the development of such a model. This interaction force is a function of a large number of parameters. Up to 32 parameters have been proposed. In addition to the large number of the parameters an analytical formulation of such a model is less likely possible, as can be seen from the past work. The complexity of the matter, therefore, calls for an empirical formulation, based on the results of experiments that must be carried out. This calls for a huge number of tests. It is important to reduce, as much as possible, the number of experiments to be performed. Also, if the material is categorized in a logical manner, various media can be prepared by mixtures of only a finite number of materials. The objective of the present paper is to define a generic function for the mathematical model and a plan for the tests that must be performed on soil type material. This leads to increased efficiency and helps to reduce duplications and unnecessary work before spending time on experiments. Based on this systematic approach the experiments can be arranged in a logical order, and the results can be later plugged in at their proper places.

KEYWORDS: Cutting/digging force, bulk media, model formulation, experiment

1. INTRODUCTION

The work discussed in this paper concerns modelling the force of cutting/digging into a bulk medium. Previous work has shown that, due to the complexity of the process and the large number of parameters, an analytical formulation is quite cumbersome, if possible. In the previous related work (see all the references) as many as 32 parameters have been considered. As such, a large number of experiments must be carried out. The intention of the paper is not to find the sought relationship at this stage; the focus is a logical decision for the experimental work in order to minimize the number of the necessary tests to be carried out.

The force we are concerned is denoted by \( f_4 \) in figure 1. This force of penetrating or cutting into a media is one of the components of the total force to be supplied by bucket (hereafter called tool for generality). The other force components are as defined in [12]. Knowledge of all the force components at any instant during an excavation task becomes necessary for automating an excavation (or loading) process [14]. Also, in other applications associated with bulk material handling, such as in their design is necessary to know the required force for cutting through and penetrating into a medium [5], [11], [13], [17], [18], [20], [23]. The necessary force to be supplied by a tool must overcome all the resisting force from the medium, one of which is the cutting force under consideration. This cutting force (or the force of interaction between a medium and a cutting tool) depends on material (properties of the medium), tool (dimensions, shape and condition such as angle of attack, operation (the way the tool moves with respect to the medium) and environment (gravity, terrain slope and temperature).

Figure 1. (a) Force components in loading a bucket, (b) force components to be provided
Numerous researchers have worked on modelling the cutting force and many formulations have been proposed. A recent survey [3], however, indicates that these models are not only incompatible, and even sometimes contradictory, most of them are not verified and none of them is universally accepted. In fact, verification of the proposed models, by itself, requires quite a lot of work. These formulations are base on mostly analytical and some experimental work. The previous work can be categorized into the studies towards the properties and the behaviour of soil for agricultural purposes or civil engineering applications [9],[10], [15], [16], [21], [24], [25], and for material handling and design of the earth moving machinery [1], [2], [6], [7], [8], [22], [26]. In all the cases, because of the complexity of the study and the large number of parameters, each researcher has followed a different approach and has made different assumptions for reducing the number of parameters. Discussing about the previous formulations, their differences or similarities, even in brief, is out of the scope of this paper.

2. PARAMETERS

The following list shows most of the parameters that have been considered in the previous works, without explaining their definition. Some of the parameters are inter-related and not all of them have equal effects. Thus, every researcher has selected and included in the formulation only a few numbers of them. These parameters are:

Tool related: Width, Tool plate thickness, Tip angle, Tip sharpness factor, Blunt edge height, Existence of teeth;

Medium related: Cohesion, Internal friction angle, Density, Elastic modulus, Poisson ratio, Compressive strength, Tensile strength, Water content (moisture), Absolute viscosity, Average particle size, Porosity, Compactness;

Operation related: Tool speed, Cutting angle (rake angle), Tool depth, Surcharge, Tool Acceleration, Failure plain parameters, Type of cutting [27], Cutting index [27], Curvature radius;

Environment related: Gravity constant, Temperature, terrain slope;

Tool-Medium related: External friction angle, Adhesion, Size factor;

There are thirty-two parameters in the above list. As for an example of the formulations suggested, the following model has been developed for bucket filling force based on a large number of experiments and considering the theoretical analysis [27]. Also, it has been cited by some other researchers, implying that it has been accepted as valid (without verification)

\[ P = f_1 = 10 C_0 e^{1.35 (1 + 2.6b)(1 + 0.0075\alpha_c)(1 + 0.03s)\alpha_0 k} \]  

(1)

where \( C_0 \) is a factor corresponding to the type of soil representing its compactness and resistance to cutting (it is based on the number of drops of a drop hammer in penetrating test; not North American standard), \( e \) is the depth of cutting in centimetres, \( b \) is the width of the bucket in meters, \( \alpha_c \) is the angle of cutting in degrees, \( s \) is the thickness of the cutting surface of the bucket in centimetres, \( \alpha_0 \) is a factor corresponding to a measure of sharpness of the cutting edge (tip angle), \( k \) is a factor representing the type of cutting (that is, two open sides, one open side or no open side). Only six parameters are employed in this formula.

In the rest of this paper first a reasonable form of the mathematical model is discussed and then a more important subgroup of the parameters are selected to be included in the model.

3. MODELLING ANALYSIS

We consider the general form of a function of several variables, all assumed to have the same degree of importance, without considering the number of variables. It is assumed, also, that no information about the relationship is available. Except for the temperature, whose effect is nonlinear and, thus, is not considered for inclusion in the model, the effect of all other parameters are continuous and none of them has a negative value. Moreover, at least for the range of practical values of these variables, no periodicity can be found. As a result, we may confidently rule out the trigonometric functions. For the sake of simplicity, we want to exclude the exponential and logarithmic functions, also. This is because of two reasons. One is because of the wide scale of variation of these functions. None of the parameters can have either a very wide range of variation or such a drastic effect that necessitates a logarithmic or exponential expression. The second reason is that we may observe the
variation of a function with respect to its one variable in one of the forms shown in figure 2 (including the mirror images with respect to the x-axis). With good approximation one may model the first and the third functions as follows (the second curve is a line):

\[
y = ax^2 + bx + c
\]
\[
y = a\sqrt{x} + bx + c \tag{2}
\]

This implies that rising and decaying exponential functions for a limited range of variation may be substituted by parabolic functions of the forms in equation 2, respectively. Furthermore, since none of the variables seems to have an effect that requires a third or higher order polynomial function, it seems reasonable to assume only first and second order polynomials. In this sense, the variation of the sought function \( y \) in terms of its \( N \) variables \( x_1 \) to \( x_N \) assumes one of the following general forms:

\[
y = \alpha_0 + \alpha_1 x_1^* + \beta_1 x_1 + \alpha_2 x_2^* + \beta_2 x_2 + ... + \alpha_N x_N^* + \beta_N x_N \tag{3}
\]

or

\[
y = a_0 \left( a_1 x_1^* + b_1 x_1 + 1 \right) \left( a_2 x_2^* + b_2 x_2 + 1 \right) \left( ... \left( a_N x_N^* + b_N x_N + 1 \right) \right) \tag{4}
\]

where the * stands for 2 or 0.5, based on equation (2). This can be quickly determined from the shape of a curve when data is available. Variation of \( y \) can be a combination of equation (3) and (4), too. At this stage, however, consideration of the more difficult case of the third version is premature. Depending on the variation of \( y \) with \( x_i \), the coefficients \( a_i \) and \( b_i \) in the first equation, or \( \alpha_i \) and \( \beta_i \) in the second equation, but not both of them simultaneously, can be zero. The task of modelling, thus, is first to determine the pattern for the variation of \( y \) with each of the variables and then to determine the values for all the coefficients. That is to say, one cannot simply deduce that the number of required experiments to be performed depends on the number of unknowns.

In general, supposing that in a controlled manner all the variables can be kept constant except one whose values are to be modified as desired, for each individual variable equations (3) and (4) assume the following forms, respectively:

\[
y = c(ax^* + bx + 1) \tag{5}
\]

and

\[
y = ax^* + \beta x + \gamma \tag{6}
\]

where \( a, b \) or \( \alpha, \beta \) denote the coefficients for any of the variables in the corresponding equation, and \( c \) and \( \gamma \) are relative constants if the values of the variable under consideration, only, are altered and the rest of variables remain unchanged. In this respect, if a series of tests are carried out in which only a parameter \( x \) is varied, in both of the above cases there are three unknowns to be found, either \( a, b \) and \( c \), or \( \alpha, \beta \) and \( \gamma \).

Theoretically, if three values for \( x \) and \( y \) are available, then the values of each unknown coefficient can be found in both of the above two cases. What is important, nevertheless, is that in each case there are \( 2N+1 \) unknowns to be determined. It is preferable if all the unknowns can be found simultaneously. Let us first review the solution to the simpler three (nonlinear or linear) equations in three unknowns, nonlinear for equation (5) and linear for equation (6).

### 3.1. Linear Equations

In the case of system (3), defined by equation (5), having three different sets of values of \( x \)'s and \( y \)'s leads to the following system of linear equations:

\[
\begin{bmatrix}
m_1 & n_1 & 1 \\
m_2 & n_2 & 1 \\
m_3 & n_3 & 1
\end{bmatrix}
\begin{bmatrix}
\alpha \\
\beta \\
\gamma
\end{bmatrix}
=
\begin{bmatrix}
p_1 \\
p_2 \\
p_3
\end{bmatrix}
\tag{7}
\]

The notation in equation (7) covers both models shown in equations (2), as well as when the function is linear (where one of the unknowns must be zero), \( m_i \) to \( m_3 \) and \( n_i \) to \( n_3 \) correspond to the variable \( x \) and \( p_1 \) to \( p_3 \) stand for the corresponding values of the function \( y \).

### 3.2. Nonlinear Equations

In the case of nonlinear equations, having three different sets of values of \( x \)'s and \( y \)'s leads to the following equations:

\[
\begin{align*}
(a + m_1 b + n_1) c &= p_1 \\
(a + m_2 b + n_2)c &= p_2 \\
(a + m_3 b + n_3) c &= p_3
\end{align*}
\tag{8}
\]

where \( m_i \) to \( m_3 \) and \( n_i \) to \( n_3 \) correspond to the variable values (here \( 1/x \)), and \( p_1 \) to \( p_3 \) stand for the corresponding values of the function (here, \( y/x^* \), etc.)
depending on the model form). Similarly, \(a\) and \(b\) stand for the unknown parameters that must be determined. Equations (8) can be solved in the following manner, by subtracting from each other, in order to eliminate \(a\):

\[
\begin{align*}
\left[ (m_1 - m_2) b + (n_1 - n_2) \right] c &= p_1 - p_2 \\
\left[ (m_1 - m_3) b + (n_1 - n_3) \right] c &= p_1 - p_3
\end{align*}
\]

which, in turn, leads to

\[
c = \frac{p_1 - p_2}{(m_1 - m_2) b + (n_1 - n_2)} = \frac{p_1 - p_3}{(m_1 - m_3) b + (n_1 - n_3)}
\]

The value of \(b\) and then \(c\) can be obtained from equation (10), and by substituting in either of the equations in (8), the corresponding value for \(a\) can be determined.

4. EXPERIMENTAL WORK ARRANGEMENT

As discussed in the previous section, we have assumed the variation of the force function \(y\) in terms of each one of the parameters to be linear or of a quadratic form. We would like to see the shape of the associated curve when necessary. For this reason, and since the results of experiments are not always 100% accurate and reliable, more points are required, even if mathematically only three points are sufficient. This suggests more experiments for the variation of each parameter. For a general discussion, this number is shown by \(H\) in the upcoming formulations. However, a value of seven (7) for \(H\) seems to be both practical and reasonable. If each parameter \(x\) can be varied in a range of values, from its lowest to its highest, the following notation will be used to denote these, not necessarily equally spaced, values:

\[x_1, x_2, x_3, x_m, x_{m+1}, \ldots, x_H\]

where the \(m^{th}\) value is around the middle of the range. For each variable \(x_i\), \(H\) experiments are necessary, where the values of \(x_i\) are varied between \(x_1\) to \(x_H\), and the values of the other variables are kept constant at their middle range, or \(m\)-values. In this way, one experiment with all the parameters at their middle value generates a common point that can be used for plotting all the function curves. Thus, the total number of experiments for \(N\) variables is \((H-1)N+1\). In the particular case of seven point curves, the total number of experiments is \(6N+1\). This number corresponds to only one curve for each variable.

In what follows for each of the two aforementioned, linear and nonlinear models, the equations to be used for the calculation of parameters are formulated and further discussed.

4.1. Linear Equations

For \(N\) variables and \(H\) number of points for each curve the linear equation containing all the \(2N+1\) unknowns assumes the form. The middle value for all parameters is a common point and is considered only once. The total number of equations is, thus, \((H-1)N+1\).

\[
\begin{bmatrix}
\alpha_1 \\
\alpha_2 \\
\vdots \\
\alpha_N \\
\beta_1 \\
\vdots \\
\beta_N \\
\beta_{H-1} \\
\beta_{H-2} \\
\vdots \\
\beta_{H-2} \\
\beta_{H-1} \\
\beta_1 \\
\vdots \\
\beta_N
\end{bmatrix}
= \begin{bmatrix}
p_1 \\
p_2 \\
\vdots \\
p_N \\
p_{H-1} \\
p_{H-2} \\
\vdots \\
p_{H-2} \\
p_{H-1} \\
p_1 \\
p_2 \\
\vdots \\
p_N
\end{bmatrix}
\]

This is an overdetermined system of \(N(H-1)+1\) equations in \(2N+1\) unknowns. It can be solved by using the pseudo inverse of the matrix on the left side. The advantage of using the pseudo inverse is that it automatically determines the least square error solution for values of unknown parameters. This is desirable. By solving equation (11) the results of all the experiments are simultaneously considered in finding the model coefficients.

4.2. Nonlinear Equations

If the same sort of notation is used for the case of nonlinear equations, the resulting system of equations assumes the form:
the first parameter, we obtain equations for each parameter, separately. The approximate values can be found by considering the set of equations (12). Equation (13) can be changed into a linear system by introducing the new variables:

\[
\begin{align*}
\left( x_{1i}^* + x_{1i} b_1 + 1 \right) c_1 &= p_1 \\
\left( x_{2i}^* + x_{2i} b_1 + 1 \right) c_1 &= p_2 \\
\vdots \quad \quad \vdots \quad \quad \vdots \quad \quad \vdots \\
\left( x_{Hi}^* + x_{Hi} b_1 + 1 \right) c_1 &= p_H 
\end{align*}
\]

where \( c_1 \) denotes the corresponding constant that results from the unchanged values of all the other parameters in equation (12). Equation (13) can be changed into a linear system by introducing the new variables:

\[
\begin{align*}
w_1 &= a_1 c_1 \\
w_2 &= b_1 c_1 \\
w_3 &= c_1
\end{align*}
\]

as a result of which the overdetermined system is in the general form

\[
\begin{bmatrix}
k_{11} & k_{12} & 1 \\
k_{21} & k_{22} & 1 \\
\vdots & \vdots & \vdots \\
k_{Hi1} & k_{Hi2} & 1
\end{bmatrix}
\begin{bmatrix}
w_1 \\
w_2 \\
w_3
\end{bmatrix}
= \begin{bmatrix}
p_1 \\
p_2 \\
\vdots \\
p_H
\end{bmatrix}
\]

(15)

Here again, by using the pseudo-inverse of the matrix \( K \) in equation (15) the minimum error solution can be found for \( w_1 \) to \( w_3 \), or accordingly for \( a_1, b_1 \) and \( c_1 \). The difficulty, however, is that a set of solutions obtained in this way must satisfy the rest of equations. More specifically, a value for \( w_i \) corresponds to all other coefficients the product of which with \( a_0 \) was called \( c_i \). If the values obtained in this way for all the coefficients \( a_0 \) to \( b_3 \) are used as a first approximation and an iterative algorithm is developed to refine these values, that can lead to an acceptable set of answers. At this time the data is not available yet and further progress on the matter cannot be made.

5. PARAMETER SELECTION/REDUCTION

Out of the parameters already cited, only the following are selected for inclusion in our model. The parameters with negligible or marginal effects can be ignored and only those parameters with significant role must be taken into account. The reason for selecting or not selecting some of the parameters is discussed below.

### 5.1. Tool Related Parameters

Tool dimension cannot be neglected since there is a direct relationship between the size of the medium affected and the size of a tool. A bucket width is to be considered. Other parameters of a tool such as tip sharpness factor and blunt edge height and tip angle are relative issues and depend on the size ratio of material particles and the tool. These are less important. The depth of cutting is considered in operation related parameters. The existence of teeth on the cutting edge of a tool is quite important and may be represented by a multiplier (teeth factor). Separate research has to be devoted to finding this factor.

### 5.2. Medium Related Parameters:

Medium related parameters are the most complicated ones. They are correlated and often uncontrollable. The same material can exhibit very different behavior towards cutting or excavation depending on its past history and other conditions. This is very true especially in the case of the interaction between water and cohesive materials. The most significant parameters are as follow.

**Cohesion and adhesion:**

Cohesion represents a measure of the internal force between the particles of a substance in bonding to each other, and adhesion is the same property but between the particles of a substance with an external (different) material, like a tool. In this sense, adhesion is indeed a medium/tool property, but for...
simplicity we want to represent these two parameters by one factor only. Both of these cause a media to resist to being cut by a tool. Also, both of these depend on the water content. The relationship with water content may be nonlinear, and other conditions may play a role. At this stage, we want to justify the selection of these parameters for inclusion in modelling.

**Internal and external friction factors:**
Friction can exhibit its effect internally or externally; that is, between the separate grains of a substance, or between these grains and an external material such as a tool. In this sense, a common factor for friction sounds reasonable.

**Other medium related parameters:**
From the numerous medium properties considered, we want to limit ourselves to density, particle size ratio and compactness as well as water content. A measure of size variation, compactness, and medium-tool size ratio must be considered. This latter can be better realized if for instance the insertion of a thin and a thick blade into a pile of sand is considered.

### 5.3. Operation Related Parameters

For each cutting operation, the angle of attack and the surcharge become more significant than other factors. Surcharge is the additional loose material on the top of the part to be cut. It has its effect on the normal stress by adding its weight. Also, it may be carried with the tool, such as in a bulldozer and grader. The speed of operation may or may not have an effect. This must be found out. The rest of operation related variables listed earlier are embedded in other factors. The depth of cutting has already been counted.

### 5.4. Tool/Medium Related Parameters

These are adhesion, external friction and tool/medium size factor. They are already considered since they can fall under tool related parameters or medium related parameters.

### 5.5. Environmental Effects

The two most important environmental parameters are the gravity constant (in case the excavation is performed in another planet) and the temperature. The slope of terrain is also an environmental effect that affects excavation. Gravity and terrain slope influence the weight component of total force of excavation. They do not have a direct effect on cutting force. Temperature has the most nonlinear influence of changing a soft rock to a hard rock only in the vicinity of freezing point and for the media with noticeable water content. Because of this special effect of temperature, it cannot be treated similar to the other parameters and, thus, it should not be included in the model.

### 5.6 Other parameters

There are some other factors, too; for example induction of vibrations to a tool and, as Zelenin has represented by a coefficient, if a medium is laterally continuous from one side or both sides are discontinuous. The issues need to be investigated separately, specially when it is obvious that their effect can be reflected by introducing an appropriate factor.

Based on the above discussion, our short list consists of: Angle of attack or cutting angle, Cohesion and adhesion, Compactness, Cutting depth, Density, Friction, Particle size distribution, Tool-medium size factor, Tool width, Water content

### 6. PRACTICAL ASPECTS

From the above list, changing the tool and the operation related parameters are the easiest ones to manage. For those associated with the media, the ideal situation is if all the properties of a material can be controlled so that they can independently assume any desired value. In practice, however, this is less likely to be possible. It has been shown [23] that certain properties of a mixture of two soils can be mathematically expressed as a function of the properties of the individual components. If this can be true for all the properties in the above short list, and if likewise it can be extended to more than two soils, then change of properties can be achieved by mixing different proportions of a selected number of base materials. In this way, any particular property can be varied within a desired range of values, while the inevitable changes in the other properties could be kept small if proper base materials can be identified.

One set of experiments is not reliable for modelling and any experiment must be repeated a number of times and with various materials for better accuracy. Not all the parameters must be treated the same way. The size of a tool or the density of the material used can be more confidently measured than say the cutting depth or the cohesion. With some different weights for the repeat of experiments, the details of which are omitted here because of space limitation we have arrived at a total number of 495 experiments to be carried out.
7. SUMMARY:

The main objective is to find a mathematical model for the cutting force that a tool encounters during excavation of a bulk material. Since, so many parameters are involved an analytical model has not been possible in the previous work and an empirical relationship must be found. This requires a great number of experiments. The purpose of this paper is first to decide about the general form of such a model and, also, to select only a subset of the parameters to be included in the model. The experimental results then can be fitted into the model. Based on the two possible models, proposed, the generic method of the calculation of the coefficients in the model function was discussed. Ten out of thirty-two parameters were determined to be more significant than others, to be included in the model. According to this work, the formulation of the model, when data is available, can be performed by first a preliminary analysis of the shape of variation of the force with each individual parameter, and then using the data in the generic model function for numeric calculation of the model constants.

8. REFERENCES


Remote Control and Automatic Monitoring
of Earth-moving Machines in Road Construction

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ABSTRACT: We report a system for remote control and automatic management of a fleet of earth-moving and construction machines with assisted guidance in earthworks and road construction. The system can be divided into three segments: control segment, positioning segment, data transmission segment. The positioning segment is based on WAAS or classical DGPS techniques. The transmission segment consists of GSM and fixed telephone network modems. The 3D positions of the machines, calculated in real time, are sensed at the control segment, at the same time as the differential corrections, by a single device built for this application. The control segment is based on a computer and a skilled operator running GIS-CAD software which controls the working accuracy of the earth-moving or operating processes with respect to the planned profile of the works. Laboratory and field tests were carried out to simulate the working performance of the system: during the tests, the 3D positions were considered with differential corrections from the WAAS/EGNOS system and with DGPS RTCM differential corrections via Internet. In this paper, we describe the system architecture and the preliminary experimental results.

KEY WORDS: Earth-moving Machines; GPS; Internet; Remote Control; Total Station; WAAS/EGNOS.

1. INTRODUCTION

There are many systems for the management of vehicle fleets and they are usually designed for specific applications. For example, Ashtech proposes a system for commercial fleets based on differential GPS positioning [Bouquet]: transmission of the positions occurs by UHF modems. For construction machinery, Caterpillar [Caterpillar] [Greene 2001], DSNP [Hintzy 1999-a] and Leica Geosystem propose solutions based on accurate real-time positioning by GPS or laser systems. In the latter examples the GPS technique is used in a direct RTK way [Greene 1998] or an inverted one [Bradley]. It is well known that this technique requires a fixed receiver connected with mobile receivers on the machines, with the exception of a system based on one-way RTK [Sharpe]. The laser systems [Peck 1995] consist of an automated total station (theodolite) placed on a point with known co-ordinates and a prism with 360° reception mirrors placed on the operating machine. During the operations the total station pursues the prism and sends its position to the control computer. The prism and theodolite must be in constant visual contact; in the presence of fixed obstacles, the theodolite is able to track the prism only when it again becomes visible.

The nominal accuracy of the two systems, usually centimetric in the plane and in height [Peck 1997] [Hintzy 1999-b], is assured inside a radius of 10 km for GPS and about 300 meters for laser systems. Unlike laser positioning, the GPS can work in all operating conditions if the receiver is able to record the signals of a sufficient number of satellites. The decreasing cost of GPS receivers, the development of differential positioning techniques based on geostationary satellites at free rent or via Internet, and the progress in wireless communication have allowed the creation of low-cost systems for the management and control of vehicle fleets. The aim of this work is to describe one of these systems, designed and built at the Engineering Department of Ferrara University, for real-time remote control of the 3D positioning of one or more construction machines, e.g. earth-moving machines used to fill road beds. The first part of the paper describes the system components while the second part reports the functional tests carried out with an agricultural tractor. The tests consider two type of DGPS positioning, the first based on use of the European WAAS system, named EGNOS, and the second based on differential corrections via Internet.
2. SYSTEM ARCHITECTURE

The system is composed of three segments: Control, Positioning and Data Transmission.

2.1 Control Segment

The control segment receives the positional data from the operating machines and transmits the messages of DGPS corrections. Its components are:
- a PC with Windows operating system;
- the commercial software Arcview 3.2 with ArcTracking extension and VisualGPS 3.33. Both programs acquire NMEA coded data of GPS receivers via a serial port and display the 3D positions of the receivers in real time on a georeference map. The software can manage many vehicles and it is also possible to record their paths to display them later on;
- an Internet/Intranet 10/100 Mb 3Com Board;
- some more or less detailed numerical maps of the test area, conveniently georeferenced.

The information is received by a modem via fixed or mobile telephony, or by Internet/Intranet. During the tests, the control segment was placed inside a building close to the test area. Figure 1 shows a photo of the control segment.

![Figure 1. Control segment](image)

2.2 Positioning Segment

The positioning segment provides real-time data on the position and velocity of the fleet. The data are transmitted to the control segment, which uses them to organise and plan the work tasks of the construction machines.

For real-time positioning of the machines, two solutions were considered:
a) automated theodolite;
b) differential GPS.

In the end we chose the differential technique in the WAAS and classic GPS modes; the latter uses RTCM corrections received via Internet. The GPS technique seemed the most suitable to satisfy the operational and accuracy requirements of construction works, usually characterised by low and medium accuracy.

The parts of the positioning segment are:
- a low-cost receiver, model Etmac Crux-2, built at the Engineering Dept. of Ferrara University [Gatti]. It is an L1 monofrequency receiver, with C/A code and 12 channels. The receiver can work in classical Differential GPS mode and Wide Area DGPS, with differential corrections from WAAS/EGNOS. In both cases the accuracy of 3D positioning is a few meters. The receiver is powered by external lead batteries, which assure 8 hours of work; in the near future it will be powered by the battery of the vehicle. The data transmission of positions can be in proprietary or NMEA formats;
- an Ashtech kinematic antenna, Marine model, part number 700700c;
- a Psion Epoc5 palmtop, with 16 Mb RAM, 37 MHz processor and monochromatic LCD screen. The palmtop, connected to the receiver by the RS232 serial port, functions as an external controller, proving to be less fragile and more handy than a portable PC;
- the palmtop runs RealMaps navigation software, which allows one to view the vehicle’s position on a map directly on the Psion’s screen. Thus the Psion and RealMaps function as a remote control unit, partly replacing the control segment.

Figure 2 shows a photo of the positioning segment.

![Figure 2. Positioning segment](image)
2.3 Transmission Segment

The transmission segment allows transmission of the positional and velocity data remotely from the machine to the control segment, and vice versa the RTCM corrections from the control segment to the machine. In general the transmission can occur via UHF radio modem, via a modem using fixed or mobile telephone networks, via geostationary telecommunication satellites or via Internet. In the absence of large obstacles, UHF radio modems allow signal reception within 10-15 km from the transmitting station. The disadvantages of radio modems are the need to install and service radio repeaters, to obtain government licences, to increase the complexity of the system with natural obstacles; the advantages are that they work even with natural disasters, which could overload and/or damage the other communication networks, the low transmission costs, the ability also to transmit digital or voice messages from/to the vehicles. Data transmission via geostationary satellites needs special devices, with higher transmission costs than mobile communications. Yet it has the great advantage of covering the entire terrestrial surface. Data transmission and reception via Internet is the most recent application [Hada]. With “Server” software it is possible to send data to a remote station using “Client” software. Both the receiving and transmitting stations must be connected via Internet.

To set up and develop the transmission segment we chose the solution based on fixed and mobile telephone networks. Two types of modem were used:
- a modem for fixed telephony, US Robotics 56k by 3COM, connected to a PC via RS232 serial port and software for serial communication. The modem adapts its transmission rate to the line conditions;
- a modem for mobile telephony, Falcom Twist, connected to the GSM network via SIM card for data transfer. The maximum transfer rate is 9600 bps, but the modem can work in GPRS mode with a higher transmission rate. However 9600 bps is sufficient for the transfer of differential corrections and NMEA data. The GSM modem has a serial port controlled by a serial communication program. The modem can also be powered by a 12 V lead battery.

Figure 3 shows a photo of the transmission segment.

Finally, Figure 4 is a block diagram of the entire system.

3. EXPERIMENTAL TESTS

3.1 Description of the test

Many laboratory and field tests were conducted to simulate the working performance of the system. The field tests were carried out at a farm near Ferrara using a New Holland TN75D agricultural tractor as a four-wheel “rover” vehicle. The test paths were chosen inside the farm.

Figure 5 shows a photo of the kinematic antenna. Detail of the GSM modem and EMTAC receiver inside the driver’s cabin.

The kinematic antenna was fixed to the top of the tractor cabin by a magnetic support (Fig. 5). The EMTAC receiver, Falcom Twist modem (to transmit the vehicle positions) and their lead batteries were placed inside the cabin. The control
station was set up in a nearby farm building and connected via a second Falcom Twist modem. In the first test the EMTAC receiver was set in WADGPS mode with reception of differential corrections from the geostationary satellite EGNOS AOR EST PRN 120. Figure 6 is a block diagram of the components used in the first test.

In the second test the receiver was set in DGPS mode, with reception of the differential corrections from the permanent GPS station of Turin via Internet [Rupprecht][Lee]. A second modem was placed in the tractor to receive the DGPS-RTCM differential corrections and direct them to another serial port of the GPS receiver (obviously different from the port outputting the positions). For the second test it was necessary to set up a second fixed station at the Engineering Department to receive the differential corrections from the Turin station via Internet and forward them to the “rover” vehicle via a US Robotics Fax Modem 56 K and the fixed telephone network. The control station used a US Robotics 56K Voice Fax modem to connect to the fixed telephone network. The block diagram of the components used for the second test is shown in Figure 7.

It can be seen that the station at the Engineering Dept. sends the RTCM transmission to the first GSM modem in the vehicle, while the second GSM modem transmits the DGPS positions to the control station where they are displayed on the map by ArcView. In both tests, NMEA messages were transmitted using GGA and GSA protocols, with a sampling rate of 1 second.

3.2 Test results

The results of the two tests were first evaluated as the percentage of positions sent to the control segment and the latency of the position transmissions, which means a delayed response of the control segment. Table 1 shows the results of both tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period [seconds]</td>
<td>1686</td>
<td>757</td>
</tr>
<tr>
<td>Position (%)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Path length</td>
<td>3,2 km</td>
<td>2,6 km</td>
</tr>
<tr>
<td>Transmission latency [seconds]</td>
<td>1,0</td>
<td>1,1</td>
</tr>
<tr>
<td>min</td>
<td>1,5</td>
<td>2,6</td>
</tr>
<tr>
<td>medium</td>
<td>max</td>
<td>2,5</td>
</tr>
</tbody>
</table>

A comparison was then made to assess the horizontal and vertical accuracy. Figure 8 shows part of the path covered by the machine during the two tests.
The positioning by EGNOS differential corrections is certainly simpler to obtain, using less resources and means; one only needs a GSM connection and two modems (Figure 6). However the geostationary satellites could be blocked by obstacles. The positioning by DGPS via Internet requires two GSM connections and thus greater means and costs. Moreover the latency increases and consequently the response time of the control segment is delayed. It is possible to acquire receivers with a bidirectional port, so that the differential corrections and NMEA positions can be received and transmitted by the same communication port. This would allow a single connection for the data transfer, but these receivers are rather expensive.

Regarding the horizontal and vertical accuracy, the DGPS positioning via Internet produces a more uniform or less spread recording than the EGNOS positioning (Figure 8). The comparison of the heights, made on the same 250 m path (Figure 9), shows an initial variation of the DGPS positioning, but after that the height differences between the two tests are nearly constant.

5. ACKNOWLEDGEMENT

Thanks to Dr. Andrea Chiorboli for the execution and description of the field tests.

6. REFERENCES


Motion planning of mounting robots with intelligent control

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ABSTRACT: High efficiency of mounting robotized complexes is achievable by means of adaptive control algorithms that provide motion planning and forming of control actions, taking into account conditions of manipulator, object and environment. Incomplete and unclear body of data on the object and operating space does not allow to obtain the desired control using traditional computational algorithms. The constructed control algorithms allow to detour the obstacles, move in straight and curve trajectories with the specified speed, to decrease the rate of construction’s movement, to perform orientation of construction and provide its smooth installation into the projective position.

KEYWORDS: robotization, construction, control algorithms, visual sensor, mobile robots, planning of the robot’s movement, kinematics.

1. INTRODUCTION

Successful problem solving of constructing-mounting operations robotization connected with orientation and installation of elements and constructions requires application of original kinematics structures combined with adaptive and intelligent control. High efficiency of mounting robotized complexes is achievable only by means of adaptive control algorithms that provide motion planning and forming of control actions, taking into account conditions of manipulator, object and environment. Control algorithms are to take into consideration many disturbing factors: orientation errors of the elements, wind load actions, limited fabrication accuracy of constructions, non-determinancy of environment, deformation of manipulation system. In the process of construction’s installation and orientation additional constraints can occur and change the plan of mounting operations. Solving of the given problems completely depends on the applied mathematical models reflecting specific character of the complex system functioning conditions. Incomplete and unclear body of data on the object and operating space does not allow to obtain the desired control using traditional computational algorithms. As a result, for control of mounting robots a problem of model construction of the mounting system arises. The model reflects real condition of mounting equipment and techno-environment.

2. CONTROL ALGORITHMS OF ROBOTS

In terms of this problem solving let us consider the questions connected with receipt of data on the environment, their processing aimed at identification of the object’s position and planning of its movement, to plan movement taking into account the running state of the environment. The prospective trend of robotic mounting complexes sensitization is application of visual sensors, developed on the basis of laser scanning systems, ultrasonic scanners or TV cameras. Visual sensors are able to provide robotic complexes with data on the operating area condition required for control and dynamically track possible changes in the real time mode. In this connection the problem of effective processing of visual information occurs to be urgent. A model of operating environment is to include data-measuring structures, controlling the object’s position and orientation, presence of obstacles on the path of its motion. Data-base of the model is to be renewed at every stage of control before movements planning. The most informative is a visual sensor, representing a TV camera, connected to a computer. The output information of such a sensor is displayed in the form of brightness points matrix of the sensor’s field of vision and
is described by indistinct set $S_0$ corresponding to the unclear condition.

$$S_0 = \left\{ \mu_{S_0}(i,j) / (i,j) \right\} \rightarrow i, j \in I,$$

where $\mu_{S_0}(i,j)$ is the truth degree of the fact that a point with coordinates $(i,j)$ of the sensor’s field of vision belongs to the obstacle or is not included into the operating area; $I = \{1,2,\ldots,m\}$ is a set of discrete coordinates, the upper level $m$ of which is determined by parameters of a technical vision system. In case the obstacles are viewed as dim-outs in the light background of the environment, the truth degree $\mu_{S_0}(i,j)$ is defined by a dim-out quantity of the point. In the simplest case $S_0$ can be considered as a square matrix of truth degrees

$$S_0 = \left\| \mu_{S_0} \right\| \rightarrow \mu_{S_0}^0 = \mu_{S_0}(i,j) \rightarrow i, j \in I.$$

In that case the vague term “dim-out” (“brightness”) shows presence or absence of the obstacle in the operating area.

Recognition of the operating area condition is carried out on the basis of comparison of the input condition with a certain set of standard conditions, stored in a specialized database. Standard conditions are selected so that every of them could cover a certain number of possible input conditions, being an indistinct union of these conditions. As a proximity measure of the conditions a degree of indistinct equality is used. In order to decrease the summable time of this problem solving, hierarchical organization of a set of standard conditions is selected. For this reason a check of proximity measure of the conditions is performed. A set of standard conditions is divided into $L$ levels, their number depending on necessity degree of presenting details in the operating area. A condition of every level is specification of the standard conditions of the previous level and is indistinctly included into these conditions. Recognition of the obstacle’s coordinates is performed by means of indistinct algorithm $A$, plotting (constructing, setting up) a correspondence between standard conditions and indistinct coordinates of the obstacle area [1]. Indistinct algorithm $A$ is specified by hierarchically organized set of conditional indistinct operators:

if $(S_0 \subseteq S_j)$, then $(x = \tilde{X}_i, y = \tilde{Y}_i)$,

if $(S_0 \subseteq S_j)$, then $(x = \tilde{X}_i, y = \tilde{Y}_i)$,

if $(S_0 \subseteq S_n)$, then $(x = \tilde{X}_n, y = \tilde{Y}_n)$,

where $S = \{S_1, S_2, \ldots, S_n\}$ is a set of standard blurred conditions; $(x,y)$ are the obstacle’s coordinates, $\tilde{X}_i, \tilde{Y}_i$ $(1 \leq l \leq n)$ are indistinct obstacle’s coordinates on orthogonal axes. Indistinct coordinates $\tilde{X}_i, \tilde{Y}_i$ represent indistinct sets in a distinct (clear) set $I = \{1,2,\ldots,m\}$:

$$\tilde{X}_i = \left\{ \mu_{X_i}(i) / i \right\}, \quad \tilde{Y}_i = \left\{ \mu_{Y_i}(i) / i \right\}, \quad i \in I.$$

The obstacles are prescribed by the expert database, and standard conditions from set $S$ are formed automatically. Standard conditions for indistinct coordinates $\tilde{X}_i, \tilde{Y}_i$ are plotted so that it was possible to cover all possible configurations of graphic primitives of the obstacles. Standard blurred condition $S_i$ is physically a certain three-dimensional area, formed by joint rotation of attribute functions $\mu_{X_i}$ and $\mu_{Y_i}$ plots around the axis, going perpendicular to the field of view plane of a visual sensor (TV camera) through point $(i_{X_i}, i_{Y_i})$, where $i_{X_i} = \arg \max_{i \in I} \mu_{X_i}(i)$,

$$i_{Y_i} = \arg \max_{i \in I} \mu_{Y_i}(i).$$

Working out of control over the constructing-mounting robot is carried out as a process of decision-making in a non-determined environment. Planning of motion is performed on the basis of discrete sequences of trajectory representation. On the basis of information about environment and the system’s own condition the aim is synthesized. On its basis control is worked out and implemented. An important property of the adaptive mounting robot is its ability to independently plan movement towards the indicated purpose position in conditions of unforeseen changes in the operating environment. Realization of such control is convenient to be performed on the basis of neuronetwork models application and considering of displacement of the mounted parts (details) in the configuration space with time dimension. The obligatory condition for
the plotted neuronetwork functioning is presence of a priori information on the environment status. Mounting works being performed in a dynamic environment, the problem of control is getting more complicated, for occasional obstacles are likely to occur while implementing trajectory movements that are to be on the neuronetwork model.

For such problems solving use the idea of a configuration space [2]. In configuration space \( C \subset R^n \) initial and purpose configuration of the mounting robot \( K_b, K_e \) are given. If at the examined moment \( t_k \) there is \( q_k \) of the obstacles in space \( C \), they are described as a field of forbidden configurations \( B_k \). This area is represented by a set of forbidden zones, every of them is described by a number of vectors:

\[
B_k = \{B_{d k}\} = \{[x_{1k}, \ldots, x_{mk}]^{(k)}, \ldots, [x_{qk}, \ldots, x_{nk}]^{(k)}\}
\]

Position of the object of manipulation in the process of movement we describe by vector \( M(t) = [m_1(t), \ldots, m_n(t)] \), bound points of movement trajectory corresponding to equalities \( M(t_b) = K_b, M(t_e) = K_e \). Planning of manipulator’s motion from initial to final point of the trajectory is implemented in accordance with condition \( M(t_b) \cap B_k = 0 \rightarrow t_b \leq t \leq t_e \). For solving the problem of planning in this case it is appropriate to use neuronetwork models; in the network dynamics they have a built-in mechanism of permanent excitation; a set of regulations for identification and indication of the robot’s next position is also prescribed [3].

At every step of control such a neuronetwork model allows to introduce updating into representation of the operating environment, taking into account occurrence and travel of obstacles in the operating area. At every step of control a new wave of activity with renewed information about environment is expected to come. The applied neuronetwork model represents a multi-layered, locally connected, parallel neuron architecture. The field of the examined network consists of a set of overlapped proximity, position of neurons is defined by \( n \)-measured vector of configuration space \( C \). Surrounding of every neuron comprises \( 2n \) of adjoining neurons, directly linked to it. Such neuronetwork model is described by a set of vectors of neurons’ condition \( X_i = [x_i, \hat{W}_{si}] \subset \mathbb{R}^{2n+1} \), where \( x_i \) - the level of neuron activation; \( \hat{W}_{si} = [w_{ij}, \ldots, w_{iq}, \hat{w}_{ij}, \ldots, \hat{w}_{iq}] \) - vector of weight factor, determining the force of synapses between neurons; \( w_{ji}, \hat{w}_{ji} \) - weight factors, corresponding to two different regulations of training. At the initial moment of time activity of all neurons and values of weight factors equal 0 (zero). According to [4] dynamics of such a neuronetwork model is described by a system of equations like:

\[
x_i(t + 1) = \zeta_i + (1 - \zeta_i) \left( \sum_{j \in s_k} \zeta_j (1 + x_j(t)) + r(\delta) \cdot (1 - \sum_{j \in s_k} \zeta_j) \right),
\]

where \( \zeta \) is an exciting outer input, associated with every neuron; \( r(\delta) \) - function, equal to \( r(\delta) = \text{mod} \left( \sum_{j \in s_k} w_{ji}(x_j(t) + 2) \right) \), if \( \delta > 0 \), otherwise \( r(\delta) = 0 \).

Planning of the robot’s movement path is carried out on the basis of the formulated regulations of weight factors change

\[
w_{ji}(t + 1) = \begin{cases} 1 \rightarrow P_k(X_{sk}(t)) > 0 \\ 0 \rightarrow P_k(X_{sk}(t)) < 0 \end{cases},
\]

\[
\hat{w}_{ji}(t + 1) = x_j(t), \ j \in s_k.
\]

The running condition of environment is reflected by means of information entering the neurons’ outer inputs. If there are any obstacles in configuration space \( C \), information \( o_j = 1 \) enters the outer inhibiting inputs of neurons, corresponding to these obstacles. Activity of the modeling network is initiated by a neuron, the excited input of which signal \( e_j = 1 \) enters. Function of priority \( P_k(X_{sk}(t)) \) provides selection of a neuron by means of successive scans of the adjoining neurons. Neuron with \( w_{ji} > 0 \) is selected as an active one. By that time its level of activity has changed, it is not associated with the obstacle and its level of activity does not exceed the one of \( i \)-neuron. The path of robot’s movement is defined by motion regulation, which can be
represented

\[ \tau(t_i + n) = \{ p_j : w_{ji} + e_j > 0, j \in S_i \} \]

Vector \( p_j \) describes robot’s configuration in space \( C \), associated by \( j \)-neuron, and train of neurons corresponds to the safe movement path.

3. STATEMENT

The constructed control algorithms allow to detour the obstacles, move in straight and curve trajectories with the specified speed, to decrease the rate of construction’s movement, to perform orientation of construction and provide its smooth installation into the projective position.

4. REFERENCES

Grab Bucet with straight linear progressive movement of jaws

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ABSTRACT: special rowing up grab buckets are used in construction for performing clearing, loading and unloading functions; when mining thin layers of soil and basic materials. The efficiency of grab buckets with large opening of the jaws can be sufficiently increased by providing straight linear progressive movement of the jaws when the angle of shearing doesn't change. The constructed control algorithms allow to detour the obstacles, move in straight and curve trajectories with the specified speed, to decrease the rate of construction’s movement, to perform orientation of construction and provide its smooth installation into the projective position.

KEYWORDS: excavating machines, construction, grab working, kinematic scheme, control algorithms, visual sensor, mobile robots, planning of the robot’s movement, kinematics.

1. INTRODUCTION

Grab working parts of excavating machines are known to be the types of a most effective equipment available. Special rowing up grab buckets are used in construction for performing clearing, loading and unloading functions; when mining thin layers of soil and basic materials. They are characterized by large opening of the jaws with the sloping path of motion and slight intrusion into the soil. The deficiency of grab buckets is the variability of the shearing angle of the cutting crimps in the process of closing the jaws that reduces the efficiency of mining.

The efficiency of grab buckets with large opening of the jaws can be sufficiently increased by providing straight linear progressive movement of the jaws when the angle of shearing doesn't change. This result was achieved due to the synthesis of a compact flat lever mechanism with progressive section suitable for using in the kinematic scheme of grab buckets of special function.

2. THEORY AND EXPERIMENT

The basis of the synthesis is simple and compact Evince mechanism connected with supplemental sections which resulted in developing the curve tongue movable straight linear directing mechanism with the section moving in the straight linear translation way.

The structural scheme of the mechanism is given in figure I: foundation 1 with a straight-
central part being connected with crank 3 by means of joint B. The other end of connecting rod 5 is joined to the connecting rod 6 the other end of which is joined to the end of the third connecting rod 7. The other end of connecting rod 7 by means of joint F is kinematically connected with crank 3. Joint F is positioned eccentrically to crank shaft on section 8 strongly linked with the crank. Joint A of crank 3 is placed on the shaft of directing mechanism 2.

When turning crank 3 in position of angle G slide 4 moves along directing (mechanism) 2 and joint C, according to the principle of action of Evince mechanism moves along shaft X. Parallelly four sectioned joint BCEF provides straight linear progressive movement of connecting rod 6, i.e. constancy of its position in angle L to shaft X, that can only be attained with the definite relation of geometrical parameters of the mechanism.

To prove this let's accept in dimensionless form the length of the second connecting rod 5 which is equal to \( l \), the length of the third connecting rod 7 is equal to \( b \), the distance between joints \( B \) and \( F \) is equal to \( \tau \) and lengths of sections \( AB=BC=BD=I \). The distance \( \tau \) and angle \( \beta \) between the shaft of crank 3 and straight-lin connecting joints B and F determines eccentricity of joint F in relation to crank 3.

In this case the current meanings of abscissa and ordinate of points E and F will accordingly be equal to

\[
\begin{align*}
x_E &= 2 \sin \varphi - l \cos \alpha, \\
x_F &= \sin \varphi - \tau \sin(\varphi + \beta), \\
y_E &= l \sin \alpha, \\
y_F &= \cos \varphi - \tau \cos(\varphi + \beta). \tag{1}
\end{align*}
\]

If intermediate values \( m = \sin \varphi + \tau \sin(\varphi + \beta) \) and \( n = m^2 + y_F^2 + l^2 - b^2 \), are assigned to the given equation then the current value of angle \( \alpha \) which follows from relation \( b^2 = (X_E-X_F)^2 + (Y_E+Y_F)^2 \) will be defined by the following expression

\[
\alpha = \arcsin \left( \frac{Y_F + \sqrt{n^2Y_F^2 - (Y_F^2 + m^2)(n^2 - m^2l^2)}}{2l(Y_F^2 + m^2)} \right) \tag{2}
\]

A straight linear progressive movement of the second connecting rod 5 is ensured if in a given diapason of the angle \( \varphi \) of a crank turning the main condition of synthesis is observed where \( l = \text{const} \). Only definite values of outlet parameters \( l, b, \tau, \beta \) correspond to it. They may be defined as a result of optimum synthesis of mechanism which can be described as follows.

Mathematical expression of the main synthesis condition may be defined as a purpose function

\[
\Delta l = l_{\text{max}} - l_{\text{min}} \rightarrow \xi \tag{3}
\]

where \( l_{\text{max}}, l_{\text{min}} \) are minimum and maximum values of the angle \( l \), defined (2) in a given angle diapason of a crank turning 3:

\[
\xi \rightarrow \text{possible change of angle } l.
\]

If additional synthesis conditions are expressed through limits on parameters \( l, b, \tau, \beta \) as inequality they establish possible ways of existing mechanism construction of intervals of uncertainty

\[
\begin{align*}
l_1 &\leq l \leq l_2 \\
b_1 &\leq b \leq b_2 \\
\tau_1 &\leq \tau \leq \tau_2 \\
\beta_1 &\leq \beta \leq \beta_2, \tag{4}
\end{align*}
\]

so in this case synthesis of mechanism may be brought up to parametrical optimum by nonlinear programming of a purpose function (3). The extreme value of the function defines optimum parameter values. Quotient derivatives of a purpose function in synthesis parameters can't be defined (obtained). So the procedure of its minimization may be fulfilled in algorithm of a, definite directed search through the use of a golden section method for intervals- of uncertainty (4) with the help of a computer (3).

In an elaborated mechanism the link 6 is used for attachment of working details to it which should be transmitted straight linear progressive movement, so the length \( l \) of the link should reasonably be chosen in a constructive way. Taking into account all that, a search of such parameter values \( b, \tau, \beta \) and \( l \) was done on a purpose function (3) and in this
case $\Delta l$ was minimum. All obtained results of synthesis of such mechanism can, be shown on the diagram (2) reflecting changeability of angle $l$ with a relative length of the link 6 that is equal to $l = 0.15$. As it is shown on the diagram in a wide angle diapason of a turning crank 3 is from $10^\circ$ to $80^\circ$ where changeability of the angle $l$ is relevant to its average value $l_b = 46.5^\circ$. It does not exceed $23^\circ$. This fact proves that a mechanism with a link moving in a straight linear direction is obtained as a result of synthesis of mechanism. The results of obtained mechanism were used in development of a grab with a large opening possibilities and straight linear progressive movement of a jaw (4). The grab shown in the picture 3 has a frame 1, that is a base of a symmetric crank of a sliding mechanism (2). Extension construction of a frame is served as a guide of mechanism. The links of mechanism are shaped as pivot farms. The grab mechanism connecting rods 5, the second connecting rods 6 and the third connecting rods 7.
The jaws (9, 10) are closely connected with the second connecting rods and joint. The grab is furnished with two pairs of hydrocylinders for opening and apart movement of jaws. The bodies of hydrocylinder for opening 11 are connected with joints 6 and their rods are connected with jaws 9 and 10. Refinements 12 and limits of jaw turning 13 are connected to the second connecting rods 6 and to the rods of a part movement hydrocylinder 15 are connected with durational pivots 14 cranks 3. The bodies of the rods are attached by brackets 16 to the bottom sides of connecting rods. The rack 17 with the cress reactor plate 18 is attached to the frame I in the bottom part which length is less than the width of the jaws. The frame is supplied with the bottom grab 19 and the top ones 20 for hanging on the basic machine in various variants on the height $h$ and $H$ through the intermediate extension piece.
The jaws are provided with the supporting rollers 21 by cleaning the surfaces with the firm covering [5]. The work of the grab is carried out as follows. The grab with the open jaws falls on the developed soil. Under effect of the rods of the hydrocylinders 15 on the cores - extension pieces 14 the curve thorns 3 rotate around the axis A, the shakers 5 and 7 make a complex movement and the four linker BCEF of the mechanism of the grab transmits a rectilinear-forward movement of the 'parts 6 together with the highly attached to them jaws 9 and 10 developing the soil. The put forward rods of the hydrocylinders 11 rest the jaws against the terminators 13 and also keep them from disclosing by the development of the soil. At the uploading place by drawing in the rods of the hydrocylinders 11 the jaws are open and the udmovable cleaners push out the soil or some other material and clean the jaws. The jaws are moved apart by drawing in the rods of the hydrocylinders 15. When falling the grab with the open jaws on the developed soil the rack 17 with the cross plate 18 take root into the layer of the soil and by closing of the jaws resist to the displacement of the frame I to the jaw’s side with the large effort of interaction with the soil at the expense of the soil shift by the cross plate to the same side. As the reaction as a result of the shift of the soil is summarized with cutting efforts of the jaw for which they are having a less meaning, an essential indemnification of the non-uniformity of the reaction of interaction between the left and the right jaw with the soil is automatically provided.
The theoretical researches were tested in the laboratory conditions on the model sample of the grab. The following initial data for the development of the grab were accepted: The capture at the complete moving apart and disclosing of the jaws - not less than 3 meters, the length of the curve horn - 90 mm the corner of the turn of the curve horns from 15 up to 75°; the relative length of lie forward link $CE = 0.15$ that corresponds to the absolute meaning of 135 mm at the given length of the curve thorn, the height of the jaw of 450 mm. Taking into consideration the original data, the optimization synthesis of mechanism of clamshell was performed by a target function (3), in the result of which was gained the following values of its parameters of crank turning angle at the range of $10^\circ$ to $80^\circ$ : The length of the third connecting rod, the distance...
between the hinges is \( EF = 1.0068 \) or 906 mm; \( FB = 0.0872 \) or 78.5 mm; angle \( \beta = 0.12^\circ \); angle \( \alpha = 46.64^\circ \); \( \Delta \alpha = \pm 2.3 \). Graphically changeability of the angle is showed in figure 2.

4. REFERENCES


3. CONCLUSION

The constructed control algorithms allow to detour the obstacles, move in straight and curve trajectories with the specified speed, to decrease the rate of construction’s movement, to perform orientation of construction and provide its smooth installation into the projective position.

Figure 2. Graphically changeability of the angle
Trajectory Arrangement of Bucket Motion of Wheel Loader

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ABSTRACT: For autonomous scooping operation by wheel loader, a method for adequate arrangement of bucket trajectory will be proposed. In scooping operation of wheel loader by human operator, bucket motion includes several cycles of arm lift and bucket tilt alternately. Consequently, the tip of bucket moves on alternate short path of horizontal and vertical direction. In this paper, relation between resistance force and advancing direction is analyzed theoretically. Advancing direction of the bucket is dominant factor for resistance force on the bucket during scooping. Based on this analysis, simple algorithm for bucket trajectory arrangement is proposed. The algorithm is implemented into small size experimental model of wheel loader. Results of the experiments show that proposed algorithm generates adequate bucket motion for different conditions of pile.

KEYWORDS: Wheel Loader, Scooping, Bucket Control, Trajectory, Resistance force, Pile

1. INTRODUCTION

A wheel loader (front-end loader) is one of the major loading machines in construction work, mining, agriculture etc. For automatic or autonomous loading operation, basic studies have been carried out and several methods for bucket trajectory generation have been proposed. One of major method is similar to the computed torque method, which is applied for control of serial link manipulators used in assembling lines[1]. In this method, the reference value for the control system is the estimation value of resistance force at the bucket based on soil-bucket interaction models. However, soil-bucket interaction models are based on estimated value of unknown factors such as bulk density, angle of internal friction etc. These factors cannot be obtained prior to scooping.

By contrast, other methods, which do not use any information on the pile or material, have been applied in field trials and shown good performance. In the scoop operation by human operator, scoop procedure consists of several cycles of arm lift and bucket tilt alternately. To realize this motion, a kind of sequence controller was installed and applied to scooping operation at asphalt plant and gravel mine[2][3]. The controller performed this cyclic bucket motion based on the resistance force at the bucket.

In ordinary scooping by wheel loader, bucket motion consists of three phases as shown in Fig.1. At the beginning of scooping, the bucket is placed on the ground. The base of bucket is kept horizontally. The bucket penetrates into the pile with advancing of the body by wheel revolution in Phase 1(A-B). In Phase 2(B-C), the tip of bucket moves upward along a line or a curve with increasing of the tilt angle of bucket. When the bucket is filled up with the pile, the bucket moves upward almost vertically in Phase 3(C-D). Determination of transfer from Phase 1 to Phase 2 and arrangement of bucket path are significant for effective scooping.

Figure 1. Bucket Path Model

In operation by human operator, it seems that when penetrating force exceeds “threshold”, Phase is transferred from 1 to 2. In Phase 2, Arm lift and tilt up are repeated cyclically. Arm lift generates
mainly forward movement of the bucket. Tilt up generates upward movement.

In this paper, these empirical operation methods is analyzed theoretically and evaluated by experiment using small size experimental model of wheel loader.

2. ELEMENTS OF FORCE ACTING ON THE BUCKET

Fig.2 shows geometrical parameters of the bucket motion and pile at scooping. Each elements of reacting force applied on the bucket are shown in Fig.3. Definition and formulations of each element are as follows;

\[ F_1: \text{penetrating force at the tip of bucket during advancing.} \]

\[ F_1 = K_0 \cos \kappa HSg \]  \hspace{1cm} (1)

Where \( H \) is depth of pile at the tip of bucket, \( S \) is cross sectional area of the tip of bucket, \( \gamma \) is specific gravity of material of the pile and \( g \) is acceleration of gravity. \( K_0 \) is coefficient related penetration resistance for each material.

\[ F_2: \text{Resistance force at bottom of the bucket.} \]

\[ F_2 \text{ appear when } \kappa > \zeta \text{ in Figure 2 however such direction or configuration are not taken at practice operation.} \]

\[ F_3: \text{weight of material in the bucket.} \]

\[ F_3 = Mg \]  \hspace{1cm} (2)

where \( M \) is mass of material in the bucket.

\[ F_4: \text{Frictional force between bucket and materials inside of the bucket. Vertical elements of force applied on inside of the bucket include that of } F_5. \]

\[ F_4 = \mu F_3 \cos \zeta + \mu F_3 \cos (\phi - \zeta) \]  \hspace{1cm} (3)

\[ F_5: \text{Force required to move material in front of the bucket. } F_5 \text{ varies depend on scooping phases. In phase 2, Material inside of the bucket forms virtual plane that push material outside of the bucket. In this case, passive soil pressure by Coulomb theory can be applied with consideration the virtual plane as the wall.} \]

\[ p_p = \frac{\gamma H^2}{2} \left( \frac{1}{\sin^2 \alpha - \delta} \times \right) \]

\[ \sin^2 (\phi + \alpha) \]

\[ \frac{1 + \frac{\sin(\phi + \delta)\sin(\phi - \beta)}{\sin(\alpha - \delta)\sin(\alpha + \beta)}} \]

\[ \text{…….(4)} \]

For formularization of elements of the force, basic experiments have been carried out. Fig.4 shows experiment system. The main component of the system is slide table driven by boll screw and DC motor. Experimental plates are attached on an end of the table and resistance force is measured during penetration into pile.
Fig. 6 is the result of flat plane penetration as shown in Fig. 5(a). Width of the plates is 150mm and thickness of plates are 2mm and 3mm. Dark line and gray line represent resistance force of 3mm and 2mm plate respectively. Thin line represents calculated frictional force obtained by extrapolation. It is clear that penetrating force $F_1$ is proportional to depth of pile and frictional force is proportional to power of the depth. Magnitude of the penetrating force is superior to the frictional force.

3. KINEMATICS AND FORCE ANALYSIS OF BUCKET LINK

In this section, kinematics and force analysis of the experimental model YAMAZUMI-2(YZ-2 Fig.8) is described. Fig. 9 shows kinematics model of YZ-2. The bucket motion mechanism consists of two links: arm link and tilt link. The bucket has three degrees of freedom with linear body motion by wheel revolution. Therefore position and configuration of the bucket are represented by functions of three valuables: advancing of the body, arm angle and tilt angle.

$$\theta = \theta_1 + \theta_2 + \theta_3$$

$$p_y = p_x \cos(q_3) + p_z \sin(q_3)$$

$$\theta_2 = q_2 + \theta$$

$$\theta_3 = q_3 + \theta$$

$$(5)$$
where \( p = (p_x, p_y, \theta_p) \) is the position vector of bucket tip, \( q = (q_1, q_2, q_3) \) is the joint vector, \( q_1 \) is the advancing distance, \( q_2 \) is the angle of arm and \( q_3 \) is the angle of bucket tilt. \( \theta_b \) is the offset angle between direction of \( l_4 \) and the bucket.

Matrix equation (6) is obtained by differentiating above equations. This equation describes relation between joint velocity and bucket velocity.

\[
\dot{p} = J \dot{q}
\]

(6)

Where \( \dot{p} \) is bucket velocity vector, \( \dot{q} \) is joint velocity vector and \( J \) is Jacobian matrix. Relation between force at the bucket and torque at each joint is described by the equation.

\[
\tau = J^T f
\]

(7)

Where \( J^T \) is transposed matrix of Jacobian. \( \tau = (\tau_1, \tau_2, \tau_3)^T \) is the torque vector and each element is the torque at each joints respectively. \( f = (f_x, f_y, n_x, n_y)^T \) is the external force vector. Operational force at the tip of bucket is obtained from equation (8) with inverse matrix of \( J^T \).

\[
f = (J^T)^{-1} \tau
\]

(8)

\( f_x \) and \( f_y \) are obtained from equation (8),

\[
\begin{align*}
f_x &= \tau_1 \\
f_y &= \tau_1 \tan \theta_2 + \tau_2 / l_2 \cos \theta_2
\end{align*}
\]

(9)

Let \( \tau_{1max} \) and \( \tau_{2max} \) be the maximum torque at wheel and arm actuators. The maximum operational force at the tip of bucket is shown in Fig.10 at a certain configuration. Each point in the polygon of operational force represents combination of \( f_x \) and \( f_y \) which are element of \( x \) and \( y \) direction of the force at the tip of bucket as described in equation (9).

4. RESISTANCE FORCE ENVELOPE AND OPERATIONAL FORCE

As described in previous sections, magnitude of the resistance force \( F_1, F_4 \) and \( F_5 \) at the bucket from pile is varied with advancing direction of the bucket. However \( F_3 \) has no relation to the advancing direction. Apparent resistance force on the bucket is integrated force from \( F_1 \) through \( F_5 \). In fig.11, magnitude of \( F_1 \) in arbitrary advancing directions is shown. In this figure, the tip of bucket is located on the origin of this coordinate system. When the bucket moves in direction \( p \), magnitude of penetration force is length of vector \( p \).

\[
\tau = \tau_{1max} \quad \text{and} \quad \tau = \tau_{2max}
\]

\( F_4 \) and \( F_5 \) have close relation to each other. As shown in Fig.12, virtual plane is supposed between materials inside and outside of the bucket. \( F_5 \) acts in normal direction to this virtual plane.

When advancing of the bucket, it pushes material on the virtual plane. Required force for the bucket movement is greater than that of \( F_5 \). \( F_5 \) is formularized by passive pressure of Coulomb theory. Direction of the virtual plane is normal to advancing direction of the bucket. Therefore magnitude of \( F_5 \) is function of the advancing
direction. On the virtual plane, no shear stress is supposed to be appeared. Hence \( F_5 \) is obtained by equation (4) with \( \delta = 0 \). Fig.13 shows magnitude of \( F_5 \) in each advancing directions.

![Figure 13. Magnitude of \( F_5 \)]

Integration of \( F_1 \) and \( F_5 \) form resistance force envelop as shown in Fig.14. It is total required force for advancing of the bucket in corresponding directions. Dotted lines represent operational force polygon. If the bucket moves indirection \( a \), magnitude of resistance force exceeds operational force. Therefore the bucket cannot move in this direction. If the bucket moves in direction \( b \), operational force is greater than resistance force and the bucket can move in this direction. Direction for intersection of resistance force envelop and operational force polygon is lower limit of advancing direction.

By advancing of the bucket, resistance force is increased proportional to increasing of depth of the pile at the tip of bucket. Then the bucket cannot move in this direction because the resistance force exceeds the operational force in this direction. However the bucket can continue advancing in upper direction because the resistance force is smaller in these directions.

5. TRAJECTORY ARRANGEMENT

Based on analysis described in previous sections, an algorithm for bucket control is installed on experimental model YM-2. The algorithm consists of simple rule: if horizontal element of resistance force exceed setting threshold, advancing direction of the bucket is arranged to upward direction. Arranged angle is proportional to exceeding value of the resistance force from the threshold.

Bucket of YZ-2 is 250mm in width, and has capacity of 2000cm³. Experimental pile is crashed granite in 5mm diameter. Specific gravity is 1.4 and internal frictional angle is 38 degree.

Fig.15 (a) and (b) show path of the tip of bucket. Inclined lines are slope of the pile. Slope angles of pile are (a) 20degree and (b) 30degree. Setting threshold for controller is 20N. In both of the cases, path of tip shows that scooping is separated into phases defined in the beginning section. Bucket motion is smooth and continuous. The proposed control algorithm generates adequate motion of the bucket for different conditions of pile.

![Figure 14. Resistance Force Envelope and Operational Force Polygon]

![Figure 15. Path of Tip of Bucket]

In phase 1, the bucket moves into pile horizontally and penetration length are 110mm in (a) and 50mm in (b). At these points, depth of pile on the
tip of bucket is 40mm in (a) and 30mm in (b). Relation between resistance force and height of the virtual plane obtained by equation (4) is shows in Fig.16. X-axis represents height of virtual plane in [mm] and y-axis represents resistance force in [N]. Dark line represents case (a) and gray line represents case (b). If resistance force is 20N, corresponding height of virtual plane is 40mm and 30mm for case (a) and (b) respectively. These depths agree with experimental results.

![Figure 16. Resistance force vs. height of the virtual plane](image1)

At the beginning of Phase 2, the bucket moves in upper direction in (b) than (a). Fig.17 shows relation between resistance force and advancing direction of bucket. Magnitude of the resistance force depends on direction significantly. Dark line represents case (a) and gray line represents case (b). If advancing direction is changed upward by 10 degrees, resistance force is reduced to half.

![Fig.17 Resistance Force](image2)

6. CONCLUSION

Relation between the resistance force and advancing direction of bucket is analyzed theoretically. The relation is formalized in the resistance force envelope and the maximum operational force of bucket motion mechanism. The advancing direction is dominant factor for resistance force on the bucket. Based on the analysis, simple algorithm for bucket trajectory arrangement is implemented on experimental model YZ-2. The result shows that the proposed algorithm generates adequate bucket motion for different condition of pile. The proposed algorithm shows good performance for different conditions in experiments however combination with bucket trajectory planning with vision system would be one of the practical solutions for application to real working sites.

7. REFERENCES

Anti-Sway Control of Suspended Loads on Shipboard Robotic Cranes

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ABSTRACT: Currently, the speed at which constructing materials can be transferred from a transport ship to an offshore construction site is limited by sea conditions. Rough sea conditions cause the payload to sway making load transfer difficult and time-consuming. The objective of this research is to develop a real-time, command compensating control for reducing sea state induced payload sway for shipboard robotic cranes. The future use of this control strategy will be to facilitate faster “ship-to-offshore construction site” payload transfer in rough sea conditions. In this study, only the sea-induced rotational motion of the ship is considered, since it is assumed that a station-keeping control maintains a constant position of the ship. This rotational motion is modelled using pitch-yaw-roll Euler angles. The shipboard robotic crane is modelled as a spherical pendulum attached to a three-degree-of-freedom manipulator. The three degrees-of-freedom are azimuth (rotation about an axis normal to the ship’s deck), elevation (rotation about an axis parallel with the ship’s deck, also referred to as luffing), and lift-line length. An inverse kinematics based approach and a sliding mode control strategy are explored. Both approaches use the azimuth and the elevation capability of the crane manipulator to maintain a horizontal position of the suspended load to reduce sea-induced payload sway.

KEYWORDS: Shipboard crane controls, Offshore construction, Inverse kinematics, Sliding mode control strategy.

1. INTRODUCTION

1.1 Overview

Currently, speed at which constructing materials can be transferred from a transport ship to an offshore construction site is limited by sea conditions. Rough sea conditions cause the payload to sway making load transfer difficult and time-consuming. Figure 1 illustrates the application. The goal of this research is to develop a real-time, command compensating control for reducing sea state induced payload sway for shipboard cranes. In the future, this control strategy may facilitate faster “ship-to-offshore construction site” payload transfer in rough sea conditions. In this study, the sea-induced rotational motion of the ship is considered, since it is assumed that a station-keeping control maintains a constant position \((X, Y, Z)\) of the ship. This rotational motion is modeled using pitch-yaw-roll Euler angles \((\gamma, \eta, \delta)\). The shipboard crane is modeled as a spherical pendulum attached to a three-degree-of-freedom robotic manipulator. The three degrees-of-freedom are azimuth (rotation about an axis normal to the ship’s deck), elevation (rotation about an axis parallel with the ship’s deck, also referred to as luffing), and lift-line length. An inverse kinematics based approach and a sliding mode control strategy are explored. Both approaches use the azimuth and the elevation capability of the crane to maintain a horizontal position of the suspended load to reduce sea-induced payload sway.

Figure 1: Ship Application.

\(^{1}\) This work was performed while the first author was a graduate student at The Michigan Tech.
In past years, several studies focusing on shipboard crane control were explored. Examples of previous works are discussed here. McCormick and Witz investigated the parametric excitation of suspended loads during crane vessel operations [McCormick 1993]. In 1979, Yumori presented results of ocean testing of the Remote Unmanned Work System [Yumori 1979]. To minimize acceleration at the boom tip, Yumori used a feedback control system with a real-time FFT cross-spectral analyzer to determine the dynamic frequency characteristic of the Motion Compensating Deck Handling System (MCDHS) and the tether cable.

Vaha et al. applied an interactive task-level control to container handling where the task description used a laser pointing system [Vaha 1988]. This method, in conjunction with an optimal control system, released the operator from continuous manual. Parker et al. introduced a successful strategy for eliminating sea disturbance induced payload sway for a 2-dimensional shipboard crane [Parker 1995]. An inverse kinematics based approach, which uses the elevation capability of the crane to maintain a horizontal position of the suspended load was developed and shown to attenuate sway using a time domain simulation.

1.2 Control System and Simulation Architecture

In this study, a simulation model is constructed to simulate the control system. The simulation structure consists of a sway dynamics block, a sway cancellation block, a crane servo dynamics block, and operator command input and a sea disturbance input. The sway cancellation block receives the sea disturbance input and the characteristic of the payload-swaying, then calculates and generates the sway cancellation command back to control the crane manipulator. The simulation architecture is shown in Figure 2.

2. SHIP/CRANE MODELING

In this section the dynamic equations of motion are developed in stages. In all formulations, Lagrange’s equations are employed.

2.1 Stationary Crane

A diagram of the crane configuration is shown in Figure 3. This crane consists of the crane pedestal, boom, lift-line, and payload. The inertial frame {I} has its origin at the ship’s C.G. with positive \( Z_I \) axis vertical with respect to gravity and the \( X_I \) axis is along the ship’s longest dimension. The \{P\} frame is attached to the pedestal, which rotates \( \alpha \) about the positive \( Z_I \) axis. The vector from the ship’s C.G. to the origin of the \{1\} frame components \( P_X, P_Y, \) and \( P_Z \) were represented in the \{S\} frame. The \{1\} frame is attached to the boom, which rotates \( \beta \) about \( -Y_P \) axis. The \{2\} frame has its origin at the end of the boom, at the lift-line attachment point. The \( Z_2 \) axis is always aligned with \( X_P \). The \{3\} frame has its origin coincident with the \{2\} frame with the \( -Z_1 \) axis along the lift-line. The \{3\} frame’s orientation, relative to the \{2\} frame, is defined by two fixed angle rotations, which are the sway degrees-of-freedom as shown in Figure 4. Specifically, the radial sway is a rotation about the \( -Y_2 \) axis. The angle of the radial sway is called “theta”, \( \theta \). The tangent sway is a rotation about the \( X_2 \) axis. The angle of the radial sway is called “phi”, \( \phi \).

The rotation matrix from the \{S\} frame to the \{I\} frame is the identity matrix
\[
{S^I}R = I .
\]
The rotation matrix from the \{P\} to the \{S\} frame is
\[
{P^S}R = R_Z(\alpha)
\]
capturing the crane’s pedestal rotation capability. The rotation matrix from the \{1\} to the \{P\} frame is
\[
{I^P}R = R_Y(\beta)
\]
capturing the crane’s luffing degree-of-freedom. The rotation matrix from the \{2\} frame to the \{1\} frame is
\[
{I^2}R = R_Z(\alpha).
\]
The rotation matrix from the \{3\} frame to the \{2\} frame is found according to the two fixed angle rotations as
\[
{Z^2}R = R_{-Y}(\theta) \cdot R_X(\phi).
\]
The payload is assumed to be a point mass and acts as a spherical pendulum.
2.2 Payload Sway Equations for a Boom Crane on a Pitching Ship

A shipboard crane model on a pitching ship is modeled by mounting the stationary crane from Subsection 2.1 on a pitching ship. The pitching ship shown in Figure 5, uses frame \( \{I\} \) has the inertial frame. The \( \{I\} \) frame has its origin at the ship’s C.G. Ship pitch is the angle \( \gamma \) measured from the \( IX \) to the \( SX \) axis. The transformation matrix of the yawing motion from frame \( \{S\} \) to \( \{I\} \) can be described as:

\[
I_S R = R_I(\gamma)
\]

and is the only change in defining \( I_P^{PL} \) as compared to the previous case.

2.3 Payload Sway Equations for a Boom Crane on a Yawing Ship

A shipboard crane model on a yawing ship is modeled similar to the crane in the pitching ship (see Figure 6). The rotational motion in the yawing ship is the rotation of frame \( \{S\} \), which is attached to the ship, to the inertial, \( \{I\} \) frame. The yawing motion rotates about the \( Z_I \) axis by an angle named “eta”, \( \eta \). The transformation matrix of the yawing motion from frame \( \{S\} \) to \( \{I\} \) can be described as:

\[
I_S R = R_I(\gamma)R_Z(\eta)
\]

2.4 Payload Sway Equations for a Boom Crane on a Pitch + Yaw Ship

In this subsection, the shipboard crane model is modeled as in the last subsection. The rotational motion of the ship combines the pitching and yawing motion with the Pitch-Yaw Euler representation. The transformation matrix of the pitching + yawing motion from frame \( \{S\} \) to \( \{I\} \) can be described as:

\[
I_S R = R_I(\gamma)R_Z(\eta)
\]

2.5 Equations of Motion

Equations of motion for each case can be determined by using Lagrange’s equations:

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = 0,
\]

where \( i = 1, 2 \)

with \( q_1 = \theta \) and \( q_2 = \phi \) are applied to this system (see Figure 4) where the Lagrangian \( L \)

\[ L = T - V \]

Is the difference between the kinetic energy \( T \) and the potential energy \( V \) where

\[
T = \frac{1}{2} m_P \left( I_P^{PL} \right)^T \left( \dot{I}_P^{PL} \right)
\]

and is the vector from the origin of the inertial frame \( \{I\} \) to the payload as shown in Figure 3, and \( m_P \) is the mass of the payload. The vector \( I_P^{PL} \) will be expressed in inertial coordinates, thereby \( I_P^{PL} \) can be computed by simply forming the time derivative of its orthogonal components. The payload position vector is

\[
I_P^{PL} = I_S R(\hat{S}_P + \hat{S}_r R_I^{PL} \hat{R_I} + \hat{S}_r R_I^{PL} \hat{R_I} R_I^{PL} \hat{R_I})
\]

where
The dynamic equations of motion are generated automatically using the MAPLE program. Full details of the equations of motion for each case can be found in [Suthakorn 1998].

### 2.6 Sea Modeling

In this study, the sea models are simulated as sinusoidal. The sea disturbances are separated into two waves; pitching and yawing motion. The amplitude of the sine waves is 10 degrees, and the frequency of this sine wave is 0.1 Hz. The pitch and yaw disturbances start at \( t=1 \) second and \( t=10 \) seconds, respectively.

### 3. CONTROL FORMULATIONS

In this section, an inverse kinematics sway cancellation control strategy and its limitation are discussed. Finally, a nonlinear control strategy is employed to solve the problem.

#### 3.1 Inverse Kinematics Based Approach

The objective of the sway cancellation control is to used the crane’s DOF to keep the lift-line vertical (with respect to gravity) thereby inhibiting the onset of sway. This is equivalent to setting \( \dot{\theta}, \dot{\phi} = 0 \). In addition, the constraint of keeping the horizontal position of the payload constant will be imposed. This allows positioning of the payload with respect to a fixed reference point.

The integration based, inverse kinematics approach may be extended to the more complicated case of additional crane DOF and disturbances. However, a potential limitation of the method is its lack of robustness. Specifically, there is no guarantee of stability if model errors are presented. Therefore a sliding mode control approach will be pursued instead.

#### 3.2 Active Sway Damping Sliding Mode Control

In an effort to express the equations and control law compactly, the following quantities are defined:

- \( \ddot{\theta}, \dot{\theta} \) vectors of the sway angles, rates of sways, angular accelerations of sways (radial sway, \( \theta \), \( \dot{\theta} \), \( \ddot{\theta} \) and tangent sway, \( \phi \), \( \dot{\phi} \), \( \ddot{\phi} \))
- \( \ddot{S} \equiv \) a vector of the sliding surface.
- \( \ddot{V} \equiv \) a vector of controller design parameters used to achieve robustness.
- \( w \equiv \) a matrix of control design gains used to set the sway time constant.
- \( a \equiv \) a matrix of the coefficients of the angular accelerations of crane’s DOF.

Using this notation the sway equations of motion in Equation (1) can be written in a compact form as

\[
\ddot{\theta} + \ddot{V} + a \ddot{\dot{\theta}} = 0 \quad (2).
\]

The desired sway dynamics are defined by the sliding surface as

\[
\ddot{S} = \dot{\theta} + w \dot{\theta} \quad (3)
\]

and

\[
\ddot{S} = \dot{\theta} + w \dot{\theta} \quad (4)
\]

where \( w = \begin{bmatrix} w_1 & 0 \\ 0 & w_2 \end{bmatrix}, \ddot{S} = \begin{bmatrix} S_1 \\ S_2 \end{bmatrix}, \dot{\ddot{S}} = \begin{bmatrix} \dot{S}_1 \\ \dot{S}_2 \end{bmatrix} \).

Substituting Equation (2) into Equations (3) and (4) gives

\[
-\dot{V} - a \ddot{\dot{\theta}} + w \dot{\dot{\theta}} = 0 \quad (5).
\]

Next, the crane inputs are solved as

\[
\ddot{\theta} = a^{-1} \left[ -\ddot{V} + w \dot{\dot{\theta}} \right] \quad (6).
\]

The final law is formed by appending the typical term, discontinuous in \( \dot{S} \), to the control law of Equation (6).

\[
\ddot{\theta} = a^{-1} \left[ -\ddot{V} + w \dot{\dot{\theta}} - A \text{sgn}(\dot{S}) \right] \quad (7)
\]

Where

\[
A = \begin{bmatrix} A_1 & 0 \\ 0 & A_2 \end{bmatrix}
\]

The crane boom and azimuth rates are obtained by integrating Equation (7) once. Stability of the closed-loop system is demonstrated using Lyapunov’s direct method. A Lyapunov candidate function is selected as

\[
\ddot{Z} = \frac{1}{2} \ddot{S}^T \ddot{S} \quad (8).
\]

For the system to be stable, it must be shown that \( \ddot{Z} < 0 \). Taking the time derivative of \( \ddot{Z} \)

\[
\ddot{Z} = \ddot{S}^T \ddot{\dot{S}} \quad (9)
\]

substitute Equation (9) from Equations (3), (4), (5), and (7):

\[
\ddot{Z} = \ddot{S}^T [\ddot{\theta} + w \dot{\dot{\theta}}] \quad (10.1)
\]

\[
= \ddot{S}^T [-\dot{V} - a \ddot{\dot{\theta}} + w \dot{\dot{\theta}}] \quad (10.2)
\]

\[
= \ddot{S}^T [-\ddot{\theta} + A \text{sgn}(\dot{S}) + w \dot{\dot{\theta}}] \quad (10.3)
\]
From Equation (10), if the diagonal elements of $\mathbf{A}$ are negative then $\dot{Z}$ is less than zero. By concepts of sliding mode control and Lyapunov’s direct method, this calculation shows that the system can be asymptotic stable when:

$$\ddot{u} = -\dot{\mathbf{V}} - \mathbf{a} \mathbf{\dot{a}}$$ (11.1)

and

$$\ddot{u} = -w \dot{\mathbf{\theta}} - A \text{sgn}(\mathbf{S})$$ (11.2)

then,

$$\mathbf{\dot{\alpha}} = \mathbf{a}^{-1} \left( -\dot{\mathbf{V}} + w \dot{\mathbf{\theta}} - A \text{sgn}(\mathbf{S}) \right)$$ (12).

The Equation (12) is used in the sway feedback approach to solve the sway cancellation in an inverse kinematics approach.

4. SIMULATION RESULTS

This section examines three types of crane systems: pitch-only, yaw-only, and pitch-yaw. The differences of each case are the sea disturbances inducing the rotational motion of the ship. A MATLAB SIMULINK time domain simulation was constructed to assess of the control system. It uses two CMEX S-FUNCTION blocks to implement the computationally intensive dynamic state update equations.

- **Pitch-Only System**
  In the pitch-only system, only radial sway will occur. Therefore, only the boom motion is used to eliminate the sway. The boom angle and azimuth angle responses are shown in Figures 7(a) and (b). Sway-cancellation on and off plots are shown in Figures 8(a) and (b), indicating a 6 dB reduction in sway magnitude.

- **Yaw-Only System**
  Although the ship experiences only a yaw disturbance, both radial and tangent sway have the potential to be excited. Because of this assumption that pitch, yaw, and roll angles are very small, the centripetal acceleration terms are zero. However, the azimuth angles are not assumed small. Therefore, the control action of the crane’s pedestal does excite radial sway which is compensated by the control system. The four plots of boom, azimuth, radial and tangential sway are shown in Figures 9(a), 9(b), 10(a), and 10(b). The tangential sway is reduced by 20 dB.

- **Pitch-Yaw System**
  In this case, pitch and yaw ship motion induces sway in both radial and tangential directions. The four plots of boom, azimuth, radial and tangential sway are shown in Figures 11(a), 11(b), 12(a), and 12(b). For this case, the amplitude of both radial sway and tangent sway are reduced by about 20 dB.

5. CONCLUSION AND FUTURE WORK

5.1 Conclusion

We presented the methodologies and results of the analysis and control design on the topic of anti-sway of suspended loads on shipboard cranes. Inverse kinematics and sliding mode control approaches were developed for sway control of multiple degree of freedom cranes. The sliding mode control was selected for final simulation evaluation due to its stability. The simulation results indicated the ability to eliminate payload sway in pitch-only, yaw-only, and pitch-yaw systems. The use of an inverse kinematics and sliding mode control approach on shipboard cranes, which have boom and azimuth capability, is effective.

5.2 Recommendations for Future Work

- Sea modeling: The sea model in this study was simulated using a sine wave. To eliminate realistic sea disturbance induced payload sway on shipboard cranes, a more realistic sea model is required. The “Simulation Time History Computer Program,” available from the U.S. Department of Defense, providing random wave time histories of 6 DOF ship responses, could be used.
- Investigating other crane configurations to actively damp sway for the full roll-pitch-yaw system.
- Additional case studies (1. different disturbance amplitudes, 2. different disturbance frequencies, and 3. same disturbance starting time) can be found in [Suthakorn 1998].

6. REFERENCES


Figure 7(a): Boom angle, 7(b): Azimuth angle histories, when the controller is on/off for the pitch-only case.

Figure 8(a): Radial sway angle, 8(b): Tangential sway angle histories with control on/off for the pitch-only case.

Figure 9(a): Boom angle, 9(b) Azimuth angle histories, when the controller is on/off for the yaw-only case.

Figure 10(a): Radial sway angle, 10(b): Tangential sway angle histories, with control on/off for the yaw-only case.

Figure 11(a): Boom angle, 11(b): Azimuth angle histories, when the controller is on/off for the yaw-only case.

Figure 12(a): Radial sway angle history, 12(b): Tangential sway angle history, with control on and off for the yaw-only case.

Variable Priority in Maze-Solving Algorithms for Robot's Movement  
(Specially useful for Low Quality Mechanic Robots)

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ABSTRACT: Most existing Maze-Solving algorithms assume a constant priority for the robot's movement. Thus, each moment, the robot will determine next movement only by the assumed constant priority. As turning would take a lot of time the fastest path and the easiest to go through is the one that has less turns. Because of the fastest path and in some projects the easiest one is preferred, and the constant priority might not lead the robot to the one with less turns, a movement priority that considers non-turning paths engenders less solving-time. In many projects the mechanic of the robot is not high quality so it should move through paths with less turns. In this paper a "variable priority for robot's movement", is introduced. This variable priority besides causing less solving-time is useful in projects that a robot with low quality mechanic is used, as it cause less turning. So, it would increase the solving efficiency a lot. One more advantage is that this manner is general and not just for a specific maze. It is important because in today's projects, most of the time, the environment around the robot is not known.


1. INTRODUCTION

Today, it is tried to use robots in more project as substitution for human. In the most of these projects, robots should move or walk and find their paths, for example robots that are used in mines or robots that are sent to planets. Therefore, nowadays, the ability of robots to consciously find their way around the terrain plays a more important role in the human life. At the present time, a maze-solving robot, self-contained without using an energy source, is more important than it was in previous years. The speed of robot to find its path, affected by the applied algorithm, acts the main part in the present projects. In these cases, the main purpose is to find the fastest path not the shortest one. And in many projects the easiest path is preferred as the robot might not having a high-quality mechanic.

In this paper the suggested method is used to increases the solving speed. These days, a lot of maze-solving robotic competitions are held around the world to achieve faster and superior robots [1], [2], [3]. To test the new method, one of these competitions is used, called "Micro Mouse" and the method is tested in this kind of competition's mazes. Flood Fill algorithm is one of the best maze solving algorithms. So, the suggested method is compared with this algorithm. After overview the problem in section 2 of this paper, the flood fill algorithm with an example is introduced in section 3. Finally, in section 4 the new method is presented and in section 5 the results are stated.

2. PROBLEM OVERVIEW

There is a movement priority in path-finding algorithms. When the algorithm permits more than one way for the next movement, the next movement direction is chosen by this movement priority. This priority in the most of existing algorithms is constant and is not changing during the process. For instance, if the destination is on the Northeast of the start point the priority shall be North, East, South and then West; or something like that. Priority is important for some reasons. The most important reason is a bad selection could throw the robot in a path with many turns. It could cause wasting extra times to find the destination and for the robots with low-quality mechanic it may cause not finding destination. Less turning is desired because turning would take time and it needs high-quality mechanic. When robot avoids undesired turning it has more time to go straight. Therefore, it accelerates more and move faster.
Considering this reason make the new method, introduced in this paper, solve the maze faster.

3. FLOOD FILL ALGORITHM

In this section the "Flood Fill" algorithm is introduced. Most of the information in this section is taken from CSUN World Wide Web about Micro Mouse [4].

The flood-fill algorithm involves assigning values to each of the cells in the maze where these values represent the distance from any cell on the maze to the destination cell. The destination cell, therefore, is assigned a value of 0. If the mouse is standing in a cell with a value of 1, it is 1 cell away from the goal. If the mouse is standing in a cell with a value of 3, it is 3 cells away from the goal. Assuming the robot cannot move diagonally, the values for a 5X5 maze without walls would look like this:

![Figure 1. Flood Fill Algorithm Explanation](image)

Of course for a full sized maze, you would have 16 rows by 16 columns = 256 cell values. Therefore you would need 256 bytes to store the distance values for a complete maze.

When it comes time to make a move, the robot must examine all adjacent cells which are not separated by walls and choose the one with the lowest distance value. In our example above, the mouse would ignore any cell to the West because there is a wall, and it would look at the distance values of the cells to the North, East and South since those are not separated by walls. The cell to the North has a value of 2, the cell to the East has a value of 2 and the cell to the South has a value of 4. The routine sorts the values to determine which cell has the lowest distance value. It turns out that both the North and East cells have a distance value of 2. That means that the mouse can go North or East and traverse the same number of cells on its way to the destination cell. As our movement priority, North, East, South then West, the mouse will choose to go to the North cell. Now the mouse has a way of getting to center in a maze with no walls. But real mazes have walls and these walls will affect the distance values in the maze so we need to keep track of them. Again, there are 256 cells in a real maze so another 256 bytes will be more than sufficient to keep track of the walls. There are 8 bits in the byte for a cell. The first 4 bits can represent the walls leaving you with another 4 bits for your own use. A typical cell byte can look like this:

<table>
<thead>
<tr>
<th>Bit No.</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td></td>
<td></td>
<td></td>
<td>W</td>
<td>S</td>
<td>E</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

So now we have a way of keeping track of the walls the mouse finds as it moves about the maze. But as new walls are found, the distance values of the cells are affected so we need a way of updating those. Returning to our example, suppose the mouse has found a wall.

![Figure 2. Flood Fill Algorithm Explanation](image)

We cannot go West and we cannot go East, we can only travel North or South. But going North or South means going up in distance values which we do not want to do. So we need to update the cell values as a result of finding this new wall. So we add one to the minimum distance value of possible cells. Now the present cell's distance value is at least one more than the rounds so the robot will move to that cell. In above example, concern to movement priority, the robot moves to the North.
Sometimes the robot goes to a cell with walls all around it. We call it "dead end". Now we "flood" the maze with new values. As an example of flooding the maze, let's say that our mouse has wandered around and found a few more walls. The routine would start by initializing the array holding the distance values and assigning a value of 0 to the destination cell.

Figure 3. Flood Fill Algorithm Explanation

The routine then takes any open neighbors and assigns the next highest value, 1.

Figure 4. Flood Fill Algorithm Explanation

The routine again finds the open neighbors and assigns the next highest value, 2.

Figure 5. Flood Fill Algorithm Explanation

A few more iterations:

Figure 6. Flood Fill Algorithm Explanation

This is repeated as many times as necessary until all of the cells have a value. It is illustrated below.

Figure 7. Flood Fill Algorithm Explanation
Notice how the values lead the mouse from the start cell to the destination cell through the shortest path.

In each cell the following steps are taken:
1. DETECT THE WALLS ROUND THE ROBOT AND SAVE THEM.
2. IS THERE ANY DEAD END?
3. IF THERE IS NOT ANY DEAD_ENDS WE SHOULD COMPARE THE CELL'S VALUE WITH ITS NEIGHBOURS TO DETERMINE WHETHER IT IS NECESSARY TO MAKE THE CELL'S VALUE PLUS ONE AND IF SO DO IT.
4. IF THERE IS DEAD_END WE SHOULD UPDATE.
5. NOW WE DETERMINE WHICH MOVEMENT SHOULD BE TAKEN.

4. THE PROPOSED METHOD

In the new method, in the part five of above division when the next movement should be determined, instead of constant priority we use a variable priority.

To define the variable priority, we placed four ultrasonic sensors around the robot; different applications may use different kinds of sensor. These sensors measure the length of the "open paths" in each side of the robot. Length of open path is the number of cells that exists in that direction without any obstacles. Higher priority is given to the direction with the longer open path. Because, in the longest open path, the robot has more time to move, accelerates more and spends less time to stop the chassis.

At the end of the execution of the Flood Fill algorithm in each cell of the maze, the final priority is selected for the next movement. At first, the Flood Fill algorithm shows which ways the robot is allowed to go through. As explained in the previous section, these ways are the ones that their distance value is fewer than the current cell's value. Each of these directions is given a digit. This digit shows the number of open path's cells in each direction. For example if the algorithm gives digit 3 to the East direction, it means that in the East direction there are three cells and then an obstacle. Then the algorithm compares these digits. So, the direction with the most open path's cells, is selected by the algorithm for the robot's next movement. This new method decrease turning a lot. Thus, it increase solving efficiency specially in such projects with the low-quality mechanic robot.

Therefore, in each cell, steps are as follows:
1. DETECT THE WALLS ROUND THE ROBOT AND SAVE THEM.
2. IS THERE ANY DEAD END?
3. IF THERE IS NOT ANY DEAD_ENDS WE SHOULD COMPARE THE CELL'S VALUE WITH ITS NEIGHBOURS TO DETERMINE WHETHER IT IS NECESSARY TO MAKE THE CELL'S VALUE PLUS ONE AND IF SO DO IT.
4. IF THERE IS DEAD_END WE SHOULD UPDATE.
5. MEASURE THE EACH DIRECTION'S OPEN PATH LENGTH.
6. COMPARE WITH THE OTHER DIGITS
7. NOW WE DETERMINE WHICH MOVEMENT SHOULD BE TAKEN (THAT IS THE ONE WITH MOST OPEN PATHS CELL).

5. RESULTS

In producing the result given in this section, a maze based on the APEC Micromouse competition rules [5] is assumed. It is just because a maze should be built for the test. But the features discussed in this paper are not dependent on the construction of the maze. Any environment in industrial and other applications could be modeled as a maze. The "Flood Fill Algorithm" with the old main priority is used as old method to solve the maze. And the flood fill algorithm beside the new variable priority is used as the new method.

We assume that the robot goes from a cell to another in 2 seconds and the time for turning is 0.5 second for 90 degrees turn. It is assumed that the robot cannot accelerate. If the robot can accelerate the solving time decreases a lot. Since in this new method, the robot goes through ways with most open path's length, acceleration can increase its speed a lot. But because of variable acceleration for variable robots and simplicity in calculations we did not assume acceleration in this test.

We showed the results in two mazes. One of them is the maze that has been used in 1996 IEE World MicroMouse Championships, University of East London, 6th July 1996 and the other one is the one that has been used in the Micromouse competition, London (Wembly) Final, July 1981. Solving these mazes with the new method and old method is illustrated below. Finally, the time needed by the robot to solve the maze is calculated by numbers of turns and movements. It is obvious this new method would help the robot to solve faster and goes through paths with less turns.
Figure 8. 1996 IEE World MicroMouse Championships solved by the old method

Solving time for this maze by the old method is $93 \times 2 + 44 \times 0.5 = 208$ sec

Figure 9. 1996 IEE World MicroMouse Championships solved by the new method

Solving time for this maze by the new method is $33 \times 2 + 14 \times 0.5 = 73$ sec

Figure 10. Micromouse competition, London (Wembly) Final solved by the old method

Solving time for this maze by the old method is $214 \times 2 + 67 \times 0.5 = 461.5$ sec

Figure 11. Micromouse competition, London (Wembly) Final solved by the new method

Solving time for this maze by the new method is $109 \times 2 + 31 \times 0.5 = 233.5$ sec
6. CONCLUSION

While there is no limitation to improve the algorithm, there are some restrictions on developing robot's mechanic or electronic. Developing algorithm is usually cheaper than the other parts. Therefore, Path-Finding algorithms, called "Maze Solving Algorithms", are the most important part in projects which a robot is used to find its path. The proposed method could not be good in some projects or could be very useful in other some but in general the variable priority would engender higher throughput and it is certainly improve the efficiency of the robot with low-quality mechanic. Future works can be concentrated on considering using variable sensors and variable methods to determine some different strategies for "variable priority for robot's movement".

7. REFERENCES


[2] APEC Micromouse Contest, held each year in United States of America.

[3] UK Micromouse contest, held each year in United Kingdom


ABSTRACT: As part of the Future Home project, research was conducted to look into ways of improving the security and develop methods and reliable systems to detect possible failures and to avoid any harm to the machinery and installations and, above all, to the workers in the construction site.

The work described in this article deals with the development of a particular security system, using both existing commercial technology and specially designed equipment.

The compulsory safety helmet required for all workers in construction sites is used as the base to accommodate miniature positioning and communication instruments (see figure 1). The position and ID of each worker is sampled periodically and sent via radio to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. According to this, workers and machines’ positions are known in each instant and risk situations may be recognized immediately and therefore damage can be prevented. If certain workers and particular machinery and equipment elements are not supposed to be in certain locations for safety reasons, an automated system can be used to detect the situation and make the adequate decision to prevent a possible accident. The proposed system is meant for modern construction systems where workers and automated/semi-automated machines coexist.

KEYWORDS: Construction Site Safety, Automatic Construction System, Positioning in Construction, IT in construction.

1. INTRODUCTION

Thousands of construction workers are injured or killed in construction accidents each year. Construction companies must inspect each site with safety engineers and provide safety programs, but unfortunately accidents still happen due to the inadequacy of these provisions. When a construction site accident occurs, the owners, architects, insurance companies and manufacturers of equipment can be held responsible for inadequate safety provisions. The general contractor and all subcontractors are required to provide a reasonably safe site, warn of hazards inherent to the site and work, hire careful employees, co-ordinate job safety and supervise compliance with safety specifications.

As part of the Future Home project [Balaguer, Atkin], research was conducted to look into ways of improving the security and develop methods and reliable systems to detect possible failures and to avoid any harm to the machinery and installations and, above all, to the workers in the work site.

The work described in this article deals with the analysis of risk sources and situations in modern construction sites and look into ways of reducing the accidents that may be caused. A security system is then proposed, and a prototype is developed and tested to prove the feasibility of the proposed scheme.

The compulsory safety helmet required for all worker in the site is used as the base to hold miniature positioning and communication instruments (see figure 1). The position and ID of each worker is communicated periodically via radio link to a monitoring station, where the information is compared to a database containing the tasks and processes being performed in the site. If a given worker is at what the system considers a hazard source it acts according to the nature of the source.
As far as the human safety is concerned, the objective is to prevent the operatives from suffering accidents related to falling or collision with dangerous objects such as moving crane loads and other machines in operation. The danger can be communicated to the worker in questions via alarm or voice using the head phones fixed to the helmet.

The following sections describe the analysis of risks, proposes a security strategy and described the developed prototype system.

2. RISKS AND SECURITY SYSTEM

One of the big challenges of new construction methods is to give a solution to all type of accidents traditionally associated to construction and to minimize new risks that may appear with the introduction of automation and robot-like machines in the worksite. According to analyzed accident statistic figures [CA3-01], the most common risks for the operatives may be reduced to: fallings, collision with mobile and fixed objects and workers trapped between objects. All these hazards are due to the continuous interaction between the workers, and the machines or any other dangerous fixed or mobile object. Once defined the risks sources, a security system may be designed to prevent accidents from happening, which should cover machines and humans.

2.1 Security Levels

As mentioned above, an adequate security system should cover two levels namely:
- Machine level
- Human level

The machine level refers to the failures in the machinery, possible erroneous operation, bad conditions of the components, etc. The main omnipresent machine in construction sites is the crane, which is the main source of possible accidents all over the world. Crane accidents claim at least 50 lives in the United States alone each year, according to data kept by the Occupational Safety and Health Administration (OSHA) besides the many more injuries they caused [CA3-01]. In particular, there are several risks associated to conventional Gantry cranes, such as failures and breaking of the cable, translation brake failures and swinging of the load. These are risks that have been taken into account during the development of the prototype crane used in this project [Balaguer]. Moreover, the position of the crane is known to the control computer and may be communicated to any other process in the construction site provided that the infrastructure can support it.

As far as the human level is concerned, the objective is to prevent the operatives from suffering the accidents related before. The strategy to adopt consist in the definition of different safe and prohibited zones around the workers and the sources of danger, so that in the moment in which these areas comes into contact a danger situation is triggered and warning is generated.

2.2 Prohibited Zones

Prohibited zones are spaces/volumes that are associated to the source of danger, which indicate that if a worker accesses it he or she risks suffering an accident. The source of danger can be a fixed or a mobile object, and therefore a distinction is made to differentiate the prohibited zones: static and dynamic prohibited zones.

2.2.1 Static prohibited zones

The dangerous volume is fixed around a given position to delimit a deep hole for example, or a fixed machine. Traditionally, the way to delimit this kind of zones is by mean of techniques like perimeter fences, light barriers, safety mats, electromagnetic induction, etc.

The disadvantages of these systems are that, as being static systems, they do not allow the entrance to the zone even when the machines are not moving, so the zone where the operatives can work is reduced.
2.2.2 Dynamic prohibited zones

In this case the prohibited zone is defined as the volume associated to a moving source of danger, such as a crane’s load (see figure 2), and therefore it moves with it.

3. SECURITY

Taking into account the fact that machines like the crane are the main source of danger present on-site, the objective of the security system is to avoid the operatives entering into the crane's operating range. It is necessary to define:

- The virtual dangerous volume around the source of danger (the crane’s load), with dimensions that are dependent on parameters such as the speed of the load and the desired level of security.
- The virtual safety volume around the operatives.
- All the equipment necessary to control these relative positions and to send the adequate orders to the machines and to the operatives in case of danger (interfaces).

All this requires a computer system to verify that there is no collision between the predefined safety zones and to stop the movement of the crane when a dangerous situation is detected.

At this point, we may differentiate between two types of security:

- **Passive Security**

  We refer to passive security to situations when the operative in danger is alerted with no intervention of the control PC.

  This security system can be implemented by equipping the crane with a radio transmitter with a pre-determined emission range. The operative wears the correspondent receiver so that, when he enters into the emission volume defined as dangerous, an alarm will be issued.

- **Active Security**

  On the other hand, we call active security when there is a control computer that drives all the security process.

  This is an appealing system, since it is possible to have a control center from which several processes are controlled with the possibility of defining all the parameters via software (ratio of...
danger, type of alarm if necessary, number of workers and machines in observation, etc.).

This PC-based control system:
- Examines the positions of the machines
- Examines the positions of the operatives
- Defines a safety margin and
- Acts consequently if that margin is broken.

Operatives can move even inside the workspace when required, provided that the particular source of danger is not present at that moment (crane load or machine moving parts) (figure 3). When the PC in the control station detects a dangerous situation it proceeds to give notice to the operatives (sonar) and machines implicated to reduce the speed or halt the operation. Such a system is able to record the evolution of movement of workers and machines to be used for further analysis when required.

4. PROTOTYPE DEVELOPMENT

To test the feasibility of the proposed security system a prototype was developed considering the above discussed ideas. The three main part that constitute the system and considered in the design are shown in the figure 4 and listed bellow:

4.1 Mobile objects

These are the crane or any other mobile machinery or tool. It is necessary to develop the system for trolley and bridge positioning, object and people identification and communications. The object used in this case is the prototype automated crane developed in this same project [Abderrahim]. The crane was equipped by positioning sensors and advanced anti-swinging control system and necessary limit switches to keep the trolley in the workspace and avoid accident. Its control computer is able to communicate the position and other information to the security control center.

4.2 Operatives

Design and development of the necessary equipment for positioning, detection and avoidance of dangerous zones, identification and bi-directional communications is implemented. The idea is to take advantage of the compulsory safety helmet and develop the necessary miniature instrument to fit in the helmet and perform the task required: positioning, voice communication, data communication, as well as radio frequency identification tag. Since the objective is the design and testing of the system rather than the hardware itself, commercial equipment were therefore used and integrated in
our lab developing the necessary components:

**Helmet:** a standard commercial construction safety helmet was used. It is readily prepared with fixing for the bi-directional voice communication system.

**Positioning:** A Garmin GPS receiver was used to detect the position. This type of measuring is adequate for open construction site and would not work inside the buildings. Any other similar positioning technique is appropriate. The position sampling in this case is 1 second; an important parameter to take in consideration for decision making regarding risk situations. The position reading is transmitted to the control center via radio.

**Voice Communication:** A bi-directional communication system (Headphones and Microphone), transmitter and receiver integrated into a high quality ear defender and hands free communication in high noise environment (figure 1). The system is adaptable for the safety helmet attachment.

**Micro Video Camera:** A commercial micro camera with omni directional antenna was used. The camera weights 20 grams (without the battery) and transmits to a distance up to 300 meters.

### 4.3 Control centre:

The control centre integrates all positioning, bi-directional communications and alarm-situation data, with a PC and Human-Machine Interface. The system can be configured and used by an operator via an intuitive graphical user interface (GUI) as shown in the figure 5. The position of the operator and the dangerous zones can be visualized by simple graphical representations. When an operator enters a dangerous zone, this can be seen on the right side of the interface. The view from the micro camera can be shown on the top left part of the interface allowing the user to see in real time the environment around the worker.

**The Radio Link to the Control Centre**

The radio link devices for the prototype presented in this work to ensure the communication between the GPS and the control centre have been built at the Robotics Lab of the University Carlos III.. The radio links for the camera and voice communication are commercially available. Sensorial information fusion is performed via software.

![Graphical User Interface in the Control Centre](image)

The result this design and integration is the whole safety system, where any collision between dangerous and safety zones is detected by the central supervision point. The system was implemented and tested with one instrumented safety helmet and produced satisfactory results.

### 5. CONCLUSIONS

Before developing the security system, a great deal of valuable information was collected and analyzed with help from construction safety experts. The results and ideas of this work are therefore realistic and applicable to a real scenario. The developed system has been tested and proved to detect potential danger of collision when an operator enters a dangerous zone. The system is able to warn automatically the operator in a potential risk position and also can use this information for other purposes. However, it is important to note that the system is a prototype and further development is expected to make it work for a number of workers on the construction site. An adequate IT infrastructure should be available on the site to allow the implementation of any modern security system.

### 6. ACKNOWLEDGMENT

The authors kindly acknowledge the valuable support received from our technical staff and in particular from A. Nombela. This work would not have been achieved without the assistance from
our partners from Dragados Construction Company, J.M. Navarro and J. Penades. Thanks are extended to J. Gamo for his effort in coding the GUI.

7. REFERENCES


[CA3-01] “Specification of an IT infrastructure to support the assessment of potential failures in site based processes” Future Home Internal Report, Department of Systems Engineering and Automation, Carlos III University, April, 2001.
The Use of Micro-Electro-Mechanical Systems (MEMS) in the Construction Industry

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ABSTRACT: Micro-electro-mechanical systems (MEMS) have been identified as one of the most promising technologies and will continue to revolutionize the industry as well as the industrial and consumer products by combining silicon-based microelectronics with micro-machining technology. All the spheres of industrial application including robots conception and development will be impacted by this new technology. If semiconductor micro-fabrication was contemplated to be the first micro-manufacturing revolution, MEMS is the second revolution. The paper reflects the results of a study about the state of the art of this technology and its future influence in the development of the construction industry. The addressed questions are: technical and economical effects of MEMS application in the industry and analysis of their use in Japan, Europe, and the USA. Also several examples of MEMS applications in construction are presented.

KEY WORDS: MEMS, Electronics, Construction, Sensors, Automation

1. INTRODUCTION

The integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology leads to what is known as micro-electro-mechanical systems (MEMS). These devices permit unprecedented levels of functionality, reliability, portability, and ruggedness at low prices. Their properties open new possibilities for the use in any branch of technology, including any construction process.

The integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology leads to what is known as micro-electro-mechanical systems (MEMS). These devices permit unprecedented levels of functionality, reliability, portability, and ruggedness at low prices. Their properties open new possibilities for the use in any branch of technology, including any construction process.

MEMS are small, integrated devices or systems that combine electrical and mechanical components. They range in size from the sub micrometer (or sub micron) level to the millimeter level, and there can be any number, from a few to millions, in a particular system. These systems can sense, control, and activate mechanical processes on the micro scale, and function individually or in arrays to generate effects on the macro scale. They are a fabrication approach that conveys the advantages of miniaturization, multiple components, and microelectronics to the design and construction of integrated electromechanical systems [Vittorio 2001].

The main advantages obtained with this technology can be condensed as: Reliability, Intelligent Products, Inexpensive Production, and Clean Production.

The paper reflects the results of a study about the state of the art of this technology and its influence in the future development of the construction industry. The addressed questions are:

- MEMS application in the construction industry
- Analysis of their use in Japan, Europe, and the USA
2. FABRICATION TECHNOLOGIES AND APPLICATIONS.

MEMS are built in ways similar to the way the integrated circuit is built. By patterning various layers of polysilicon as they are deposited, and releasing part of the structures, the devices are capable of motion. The MEMS industry has employed three distinct processing technologies, more or less defined by the height of the finished structure [Singer 2002]: bulk micro-machining, surface micro-machining, and a process commonly known as LIGA, an acronym from the German words for lithography (lithografie), electroplating (galvaniformung) and molding (abformung). For most of the highest-volume applications, there has been a tendency to use surface micromachining, not only because it makes it easier to integrate circuitry with the device, but also makes it possible to use the same equipment developed for IC manufacturing.

MEMS devices have a wide range of application, covering from medicine, computers and communication to manufacturing systems. Some of them are:

- Micro-robots
- Gyroscopes
- Micro-optical systems for fiber-optics communications
- Switches, varactors, inductors, and resonators
- Micro-tweezers
- Neural probes
- Accelerometers
- Pressure Sensors
- Micro-engines

2.1. Pressure Sensors

Pressure sensors normally have a flexible diaphragm that deforms in the presence of pressure difference. The deformation is converted in an electrical signal that appears at the sensor output. The MEMS pressure sensors frequently use the piezoresistive effect. Due to this, the change in electrical resistivity that occurs with application of mechanical stress produces changes in electrical variables at the device’s output. A more detailed description can be found in [Silicon Microstructures, Inc].

On figure 1 it is shown the fraction of the total that corresponded to accelerometers, gyroscopes, and pressure sensors in US in the year 2001 and the expected value in 2008 [Carrillo].

![Figure 1. Total MEMS Sensor Market in US](image)

2.2. Pavement condition monitoring

A very interesting application is presented by Attoh-Okine [Atto-Okine 2002]. The analysis of the use of MEMS for collecting data reflecting the conditions of the pavement is performed. The idea is based on the introduction of microsensors in the asphalt to monitor parameters critical to the safe operation and performance. The system consists of a network of sensors embedded into the pavement structure. The collected data is transmitted via low power radio link to a receiver and data logger located on the side of the road. As was reflected in the previous cited paper, several issues have to be considered when applying this technology for pavement condition monitoring. Among them are cited: the effect of asphalt medium on MEMS, where these devices will be embedded in the pavement, how long will last the devices, and how much will cost this method of collecting data.

2.3. Flaw detection in structures

Many devices have been developed for flaw detection, using laser, fiber optics, etc. Ultrasonic flaw detectors are also used, based in the Doppler principle. When using ultrasonic detectors, several variables affect the ability of ultrasound to locate defects. These include the frequency of ultrasound.
impulses, pulse length, type and voltage applied to the crystal, properties of the crystal, backing material, transducer diameter, and the receiver circuitry of the instrument. Among the different options for detecting flaws in metallic structures, the use of capacitive sensors [Jain 2002] appears like a very interesting one. The device uses a capacitive MEMS transducer, where a diaphragm deflection produces a change in the capacitance that can be detected electrically. The authors have developed a resident ultrasonic flaw detection system to be mounted at critical locations on metal structures. The device is polled remotely using RF communication. The chip is approximately 1-cm square and contains 23 detectors. In the tests commercial ultrasonic transducers with operating frequencies of 3.5 MHz and 5 MHz were the signal sources.

2.4. Bulk and Surface Acoustic Wave Sensors

Using piezoelectric MEMS as transducers of different physical properties employing silicon offer many advantages. Ivanov analyzes the characteristics of advanced sensors for detecting simultaneously various parameters such as temperature, pressure, electric and magnetic fields, etc [Ivanov 2000]. These sensors provide not only high signal-to-noise ratio in a wide dynamic range but also well cross-sensitivity.

Bulk and surface acoustic wave resonators have been used extensively in the design of multifunctional physical and chemical sensors. Because frequency may be measured with higher accuracy than any other parameter, mechanical resonators are well suited for the design of high-sensitivity sensors. A resonator without any load film, in vacuum behaves like an unbounded, stress-free plate. If the resonator is loaded with a thin film, the boundary conditions will be modified. A dielectric film modifies mechanical boundary conditions, while a conducting film modifies both mechanical and electrical boundary conditions. Mechanical and electrical perturbations cause resonant-frequency shifts. The regime of oscillation of a piezoelectric resonator can be modified by mechanical or electrical perturbations originating from the surrounding medium. As indicated by Ivanov, “when a free quartz resonator is brought in contact with a solid or fluid medium, some acoustic energy is drained out of the resonator, resulting in damping of the oscillations. The acoustic coupling with the loading medium and the amount of acoustic energy returned back to the resonator defines the resonance frequency shift. Loading a quartz resonator may result in a decrease of the Q-factor, a resonance frequency shift or both effects at the same time”.

This property can be used for creating MEMS devices which, embedded in the building structure, can detect and store information related to fatigue or any change in the medium characteristics.

3. DEVELOPMENT OF MEMS TECHNOLOGY IN USA, EUROPE, AND JAPAN

MEMS devices have successfully established high-volume commercial markets including accelerometers and pressure sensors for automotive applications, inkjet print heads, and digital micro-mirrors for image projection. In addition to major industry players, there exist many research institutes, government and private laboratories, and universities all around the world, pursuing researches related to this technology. A geographical breakdown on MEMS fabrication is given in Figure 2 [Yole 2003]. As can be seen, from this data, the US occupy the first place, followed by the European countries and in third place, Japan.

Figure 2. Geographical Breakdown of MEMS Fabrication

Data published from a study of the NEXUS Task Force [MCC/WTEC 2000] show that in Europe “the automotive sector was the market driver in the first phase of MEMS commercialization, but has been supplanted by the IT peripherals sector (including
HDD read/write heads and inkjet print heads). Biomedical, telecommunications, mass storage, and display applications are increasing their volume. The device classes being pursued mostly, as per [WTEC Hyper-Librarian], fall into the following categories: Fluidic MEMS, Mechanical Transducers, Optical MEMS, and Electrical MEMS Switches.

Japanese programs have been significant in the development of sensors, actuators, and MEMS in the past through programs at a number of universities and companies, and the leadership of Japanese industry in consumer products puts them in an excellent position to benefit from MEMS technology.

During year 2000, the MEMS industry in USA was estimated from 2 to 5 billion dollars, and in 2004 should grow up in the order of 12 to 15 billion dollars. It is expected that in 2004 there will be 5 MEMS devices per person in the country. In year 2001, 163 companies were established with a total of 6000 employees [Yole 2003]. This numbers have been growing every year.

4. SOME CHALLENGES

Packaging MEMS-based sensors is the critical issue that has and will have a strong impact in the North American MEMS-based sensors market. This challenge is crucial in industries such as the medical and process control. Consequently, MEMS sensor manufacturers need to build their own packaging, which translates into high manufacturing costs as opposed to the standard integrated circuit (IC) packaging technology, which tends to be more cost-effective when mass-producing sensing devices. The packaging of MEMS-based sensors is probably the greatest challenge facing the MEMS industry [MEMS 2002].

MEMS are too small for traditional batteries. These batteries must fit inside devices smaller than the width of a human hair and provide long-lasting power. A way of solving this problem is proposed by Bruce Dunn. He proposes changing from two-dimensional sheets of electrodes to rods arranged in a three-dimensional array in which hundreds of rods are stacked next to each other like tubes on a flatbed truck. Each rod is only a thousandth of a centimeter in size. The group is currently designing a battery five millimeters in size, which presents significant design challenges [UCLA 2002].

5. CONCLUSIONS

The development of MEMS is demanding higher levels of electrical-mechanical interaction, as well as a higher level of knowledge of the physical world. Their use increases the systems’ properties like reliability and level of integration. The development of microdevices in which are embedded the electronic circuits, sensors, actuators and engines, open new ways of solving industrial problems at lower cost and increased quality.

MEMS sensors utilization permit to avoid the necessity of point-to-point wiring, realizing a digital output format, and obtaining greater precision. Embedded sensors in different type of structures permits the creation of what is called “smart structures”, which can be used in civil and mechanical engineering projects.

The US is the country realizing more investments in this direction, followed by the European community and Japan. The major field of application of MEMS in industry is in first place different type of sensors. Also the wireless MEMS because they offer the possibility of achieving significantly lower power consumption and more compact integration.

There are challenges to face in the introduction of MEMS in the market. Among them, the packing, small and long-lasting batteries, and their behavior under different environmental conditions.
6. REFERENCES


[WTEC Hyper-Librarian]. WTEC Hyper-Librarian. The State of the Art in Europe.
Design and Analysis of a New 7-DOF Parallel Type Haptic Device: PATHOS-II

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• ABSTRACT: Most tele-operation to manipulate an object consists of gripping and manipulation and two or more 6-DOF haptic devices in master side are usually used. In this article, a new simply designed 7-DOF haptic device, PATHOS II is proposed for 1-DOF gripping and 6-DOF manipulation. The merits of a parallel type haptic device such as high stiffness and accuracy are natural characteristics of PATHOS-II with optimized workspace. Due to its unique symmetric structure, the isotropic manipulability is enhanced within the reachable workspace. This parallel type haptic device can be used in applications which need high resolution, stiffness and isotropic manipulability.

KEYWORDS: Haptic Device, Parallel type, 7 DOF Robot.

1. INTRODUCTION
A haptic device is an instrument to convey operator's command to slave manipulator and produce sensation to make an operator feel the situation of the slave side. Recently, the number of applications of tele-operation is growing in various fields of micro manipulation, tele-surgery, virtual training, and outdoor robotics. Haptic devices can be classified into glove type [glove_type], exoskeleton type [exoskeleton_type], and pen type [pen_type] by the way of transmitting sensation or serial type [pen_type], parallel type [parallel_type], and magnetic levitation type [magnetic_type] by the structure or the way of generating sensation. The type of haptic device is determined by the purpose of their required function.
In tele-operation, most of task procedure is: the operator moves the slave manipulator near the target, grasps the object, and manipulates it using two or more haptic devices. For the purpose of the task, two 6 DOF haptic devices are usually used.

However, it is redundant to use two haptic device for the task. In this article, a new parallel type haptic device for 6-DOF motion and force reflection with 1-DOF pinch grasping, PATHOS-II (Postech pArallel Type Haptics Operating System), is proposed. Figure 1 shows that it is possible to do the task with a PATHOS-II. The most important reason to use parallel structure in haptic device is its high stiffness compared to serial type. With this characteristic, the haptic device can not only display high force feedback but also generate elaborate motion with high accuracy. In spite of the merits, there are tradeoff like complex kinematics, small workspace, isotropy, and singularity problems. PATHOS-II is designed simply with only revolute joints to minimize above mentioned complex kinematics. Since it has simple structure, it is easy to solve kinematics and computational load becomes lower. Especially, with only 9 sensors among 25 joints, forward kinematics of 7-DOF can be obtained as will be stated in section 2. In order to maximize the workspace of PATHOS-II, link ratio and initial orientation are optimized. The workspace covers the human haptic manipulation [khkhaptics] as will be stated in section 3. Isotropy is another important factor to determine whether the designed device can be used as a haptic device. In order to guarantee similar isotropic stiffness, PATHOS-II was designed to have symmetric structure. Active joint direction vector is also considered. As a result, uniform isotropic property of PATHOS-II is mentioned in section 4 and conclusion follows.

2. Kinematics
PATHOS-II was designed symmetrically with 6 legs which consist of only revolute joints and as a result, the kinematics is simple to solve. In this
section, structure of PATHOS-II is explained and inverse and forward kinematics with 9 sensors will be shown.

Figure 2. PATHOS-II and a leg

2.1 System Description
The leg of PATHOS-II has 3 revolute joints and 1 globular joint which has 3 revolute joints as shown in Figure 2. The revolute joint at the end of a leg, R1, is fixed on base plate and the globular joint is fixed on top plate. Figure 3 shows the structure of PATHOS-II. The number in circles on base plates denotes the position of leg and globular joints are also located on top plate in the same order. Then, PATHOS-II has 21 links(3 links in each leg, 1 base plate, and 2 top plate), 25 joints(1 globular and 3 revolute joints in a leg and a joint in top plate). From Freudenstein and Maki’s method for spatial mechanism\(^1\)

\[ F = 6(L - J - 1) + \sum_{i=1}^{J} f_i \]

\[ = 6(21 - 25 - 1) + 1 \times 3 \times 6 + 3 \times 6 + 1 \times 1 \]

\[ = 7(\text{DOF}) \]

The first joints of each leg, R1 in Figure 2, are active joints. h_0 is half of distance between top plates in Figure 3. It is changed by an operator grasping motion. Therefore, PATHOS-II needs 6 actuators at the first joint of each leg and one between top plates for force feedback. If h_0 in Figure 3 becomes constant when an operator grips an object, F becomes 7(\text{DOF}).

and 6 DOF manipulation of an object is possible.

2.2 Inverse Kinematics
In Figure 3, X-Y-Z coordinate at the center of base plate is the reference and x-y-z coordinate fixed at the center of top plate is used to describe the pose of end effector. Those coordinates are common to every leg. One leg has the following transformation from reference coordinate to the pose of end effector.

\[ \begin{bmatrix} T_1 \end{bmatrix} = \begin{bmatrix} T_z(L)R_x(\theta_{b1})R_z(\theta_{b2})T_z(l_1)R_x(\theta_2)T_z(l_2)R_z(\theta_1) \end{bmatrix} \]

\[ = T_z(l_1)R_x(\theta_2)T_z(l_2)R_x(\theta_3)T_z(l_3)R_z(\theta_4)R_y(\theta_5)R_z(\theta_6) \]

T \text{ and } R \text{ in Eq.(1) are homogeneous transform which mean translation and rotation. } T_z \text{ means translation in } x \text{ direction and } R_y \text{ means rotation about } x \text{ axis. } L \text{ is 0 for 1st to 3rd leg and 1}_0 \text{ for 4th to 6th leg. } l_0 \text{ is the distance between base plates. } \theta_{b1} \text{ is 0° for 1st to 3rd leg and 180° for 4th to 6th leg. Other variables in Eq.(1) are shown in Figure 3. If the system is determined, all terms of Eq.(1) are known except } \theta_i (i=1,2,3,4,5,6). \]

From Eq.(1), we can find the position closure and position vector, \(a\) in Eq.(2) is known.

\[ R_x(\theta_1)T_z(l_1)R_y(\theta_2)T_z(l_2)R_z(\theta_3)T_z(l_3) = \begin{bmatrix} x & a \end{bmatrix} \begin{bmatrix} 0 & 1 \end{bmatrix} \]

Hereafter, orientation part and translation part of homogeneous transform will be used for R and T, respectively. R is a 3×3 matrix and T is a 3×1 vector. Then, Eq.(2) becomes

\[ R_x(\theta_1)T_z(l_1) + R_y(\theta_2)T_z(l_2) + R_z(\theta_3)T_z(l_3) = a. \]

Eq.(3) can be represented by the following 3 equations.

\[ R_x(\theta_1)C_1 = a, \]

\[ C_1 - T_z(l_1) = R_y(\theta_2)C_2, \]

\[ C_2 - T_z(l_2) = R_z(\theta_3)T_z(l_3). \]

In matrix form, it is

\[ \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 \end{bmatrix} \begin{bmatrix} c_{1x} & c_{1y} & 0 \end{bmatrix} = \begin{bmatrix} a_x \end{bmatrix}, \]

\[ \begin{bmatrix} S\theta_1 & C\theta_1 & 0 \end{bmatrix} \begin{bmatrix} c_{1y} & c_{1z} & 1 \end{bmatrix} = \begin{bmatrix} a_y \end{bmatrix}, \]

\[ \begin{bmatrix} C\theta_2 & 0 & -S\theta_2 \end{bmatrix} \begin{bmatrix} c_{2x} & c_{2y} & c_{2z} \end{bmatrix} = \begin{bmatrix} a_x & a_y \end{bmatrix}, \]

\[ \begin{bmatrix} S\theta_2 & C\theta_2 & 0 \end{bmatrix} \begin{bmatrix} c_{2y} & c_{2z} & 1 \end{bmatrix} = \begin{bmatrix} c_{1x} \end{bmatrix}, \]

\[ \begin{bmatrix} -S\theta_2 & 0 & C\theta_2 \end{bmatrix} \begin{bmatrix} c_{2z} & c_{2y} & c_{2x} \end{bmatrix} = \begin{bmatrix} c_{1y} \end{bmatrix}. \]
From Eq.(5-6), and (7), the equivalent 6 equations are

\[
\begin{bmatrix}
1 & 0 & 0 \\
0 & C\theta_3 & -S\theta_3 \\
0 & S\theta_3 & C\theta_3
\end{bmatrix}
\begin{bmatrix}
c_{2x} \\
c_{2y} \\
c_{2z} - l_2
\end{bmatrix} =
\begin{bmatrix}
0 \\
0 \\
l_1
\end{bmatrix} .
\] (7)

These give \( \theta_4, \theta_5, \) and \( \theta_6 \) and this procedure is applied to every leg.

After some calculation with Eq.(8) to (13), coefficients are,

\[
c_{1x} = \pm \sqrt{a_x^2 + a_y^2 + a_z^2},
\]

\[
c_{1y} = c_{2y} = \pm \sqrt{l_3^2 - (c_{2z} - l_z)^2},
\]

\[
c_{1z} = a_z,
\]

\[
c_{2x} = 0,
\]

\[
c_{2y} = \pm \sqrt{l_3^2 - (c_{2z} - l_z)^2},
\]

\[
c_{2z} = \sqrt{l_3^2 - l_z^2} + a_x^2 + a_y^2 + (a_z - l_z)^2 / 2l_z .
\] (14)

Then, \( \theta_4, \theta_5, \) and \( \theta_6 \) are solved from Eq.(9), (11), and (13) with coefficients in Eq.(14).

Then, in Eq.(1), only 3 terms, \( \theta_4, \theta_5, \) and \( \theta_6 \) are unknown. To find them, the following equations are derived.

\[
R_z(\theta_4)R_y(\theta_5)R_z(\theta_6) = B =
\begin{bmatrix}
b_{11} & b_{12} & b_{13} & 0 \\
b_{21} & b_{22} & b_{23} & 0 \\
b_{31} & b_{32} & b_{33} & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}.
\] (15)

The matrix B is known from Eq.(1). After multiplying \( R_z(\theta_4)^{-1} \),

\[
\theta_4 = \tan^{-1}\left( \frac{b_{23}}{b_{13}} \right),
\] (16)

\[
\begin{bmatrix}
C\theta_5 \\
S\theta_5
\end{bmatrix} =
\begin{bmatrix}
b_{31} \\
b_{32}C\theta_4 + b_{33}S\theta_4
\end{bmatrix},
\] (17)

\[
\begin{bmatrix}
C\theta_6 \\
S\theta_6
\end{bmatrix} =
\begin{bmatrix}
-b_{13}S\theta_4 + b_{23}C\theta_4 \\
-b_{13}C\theta_4 + b_{23}S\theta_4
\end{bmatrix}.
\] (18)

2.3 Forward Kinematics

Forward kinematics is to find the pose of top plate and top plate length, \( h_0 \) in Eq.(1) from the sensor information. PATHOS-II uses 9 sensors to solve 7-DOF forward kinematics.

The locations of sensors are shown in Figure 4. In Eq.(1), \( T \) and \( T_z(-h_0) \) on the right hand side for 1st, 5th, and 6th leg are unknown. The positions of globular joints of 1st, 5th, and 6th leg, \( a \) in Eq.(2), which has 3 sensors can be calculated.

Then, Figure 5 shows the top plate and vertices mean the positions of globular joints of each leg. In other words, \( P_1(x_1,y_1,z_1), P_2(x_2,y_2,z_2), P_3(x_3,y_3,z_3) \), and \( P(x,y,z) \) are positions of globular joints of 5th, 6th, and 1st leg, respectively. First, from the points, \( P_4, P_2, \) and \( P_3 \), \( h \) can be calculated as followings.

\[
h = \sqrt{(x_1 - x_3)^2 + (y_1 - y_3)^2 + (z_1 - z_3)^2 - 3r^2}.
\] (19)

The point P can be calculated as
\[
\begin{bmatrix}
2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\
2(x_3 - x_2) & 2(y_3 - y_2) & 2(z_3 - z_2) \\
2(x_1 - x_3) & 2(y_1 - y_3) & 2(z_1 - z_3)
\end{bmatrix}
\begin{bmatrix}
x \\y \\z
\end{bmatrix}
\]

\[
3 \beta^2 - 9 \beta^4 + (x_1^2 + y_1^2 + z_1^2) - (x_2^2 + y_2^2 + z_2^2)
\]

\[
\Delta \theta_{h_2} = 120^\circ \\
\Delta \theta_p = 120^\circ \\
l_x = l_y / \cos \theta_i \\
l_p = l_z / \sin \theta_i
\]

The value of cost function is calculated by increasing \( l_2, l_3, l_p, \) and \( R_z \) with the steps within ranges in table 2. Then, if collision between legs or exceeding the joint angle limit is happened during finding \( \Delta L_x, \Delta L_y, \) and \( \Delta L_z \) in Eq.(21), the results are excluded. Cost function was maximized when \( l_2 = 14.0, l_3 = 6.0, l_\delta = 2.0, \) and \( R_z = 30.0^\circ \).

Table 2. Given ranges of variables to find \( \Delta L_x, \Delta L_y, \) and \( \Delta L_z \)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Lowest limit</th>
<th>Upper limit</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l_2 )</td>
<td>0.0</td>
<td>20.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( l_3 )</td>
<td>0.0</td>
<td>20.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( l_p )</td>
<td>0.0</td>
<td>20.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( R_z )</td>
<td>0(^\circ)</td>
<td>120(^\circ)</td>
<td>15(^\circ)</td>
</tr>
</tbody>
</table>

3.2 Workspace

Now, link ratio and initial pose are determined after the optimization of cost function of Eq.(21). However, PATHOS-II is designed to change the length \( l_0 \) in Figure 3. Figure 6 shows the workspace when \( l_0 \) is changed from 40.0 to 55.0. The workspace increases when \( l_0 \) becomes smaller.

Table 1. Given pose to find \( \Delta L_x, \Delta L_y, \) and \( \Delta L_z \)

<table>
<thead>
<tr>
<th>( l_0 )</th>
<th>50.0</th>
<th>( x )</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l_\delta )</td>
<td>10.0</td>
<td>( y )</td>
<td>0.0</td>
</tr>
<tr>
<td>( l_\perp )</td>
<td>7.0</td>
<td>( z )</td>
<td>25.0</td>
</tr>
<tr>
<td>( h_0 )</td>
<td>7.0</td>
<td>( R_x )</td>
<td>0.0</td>
</tr>
<tr>
<td>( \Delta \theta_{h_2} )</td>
<td>180(^\circ)</td>
<td>( R_y )</td>
<td>0.0</td>
</tr>
</tbody>
</table>

\( \Delta L \) and \( \Delta \theta \) in Figure 6 denote the workspace in which inverse kinematics is obtained continuously.

Figure 6. (a) : Workspace for fixed initial orientation, (b) : Workspace for fixed position

\( \Delta \theta \) in Figure 6 denote the workspace in which inverse kinematics is obtained continuously.
For example, $\Delta L$ in Figure 6.(a) is the movable range of each direction when orientation is fixed in initial pose. However, for small $l_o$, space for human grip decreases and collision between human hand and legs is expected. $l_o = 45.0$ is suitable to avoid collision and maximize workspace.

In fact, the workspace can be increased as the links become longer. So, the workspace is compared to the haptic device size. The dimension of PATHOS-II is a cylinder shape of 20.0cm radius and 45.0cm height and the workspace is about a sphere of 14.0cm diameter which can cover the human haptic manipulation range[khkhaptics]. However, this reachable workspace cannot be used because of manipulability and isotropy. In the case of PATHOS-II, this reachable workspace can be almost used in the viewpoint of isotropy. It will be explained in the next section.

4. Isotropy

Another important requirement for a good haptic device is isotropy which makes handle move to any direction an operator wants or guarantees similar stiffness of an haptic device toward every direction.

$$\dot{x} = J\dot{q}$$

(22)

where

$$\dot{x} = [\dot{x} \ \dot{y} \ \dot{z} \ \omega_x \ \omega_y \ \omega_z]^T,$$

$$J = [J_p \ J_o]^T,$$

$$\dot{q} = [\dot{q}_1 \ \dot{q}_2 \ \dot{q}_3 \ \dot{q}_4 \ \dot{q}_5 \ \dot{q}_6]^T.$$ 

$$\delta q \cdot \tau = \delta x^T \cdot F,$$

$$\tau = J^T \cdot F.$$  

(23)

Eq.(22) and (23) show velocity and force relations between task space and joint space. $\dot{x}$ and $\dot{q}$ mean velocities of task coordinate and active joint angles. Though PATHOS-II has 7 actuators, since $\dot{h}_o$ is constant when an operator grips an object, it is reasonable to consider 6-DOF spatial task space. The Jacobian, $J$, is decomposed to $J_p$ and $J_o$ which are $3 \times 6$ matrices related to velocity and angular velocity since position and orientation have different dimensions. After singular value decomposition, condition number which is the ratio of maximum and minimum singular values means isotropy of velocity and angular velocity or force and moment. For example, if condition number is close to 1, system is isotropic at the attitude. If its condition number becomes large or singular, the haptic device is not a structure any more, since force reflecting is not available. To be a nice haptic device, it should be isotropic in every attitude in its workspace.

Though PATHOS-II is designed to have symmetric structure for isotropy, the stiffness in Z direction in Figure 3 can be lower than other directions if the direction vector of active joints is aligned to $z$ direction. So, $\theta_i$ needs to be determined to make PATHOS-II have similar stiffness in every direction and $\theta_i$ is selected as 30°.

Condition numbers of PATHOS-II in 6 plane are shown in Figure 7 and 8 which are obtained from $J_p$ and $J_o$, respectively. (b), (d), and (f) are projection images of (a), (c), and (e) to the plane. For example, to draw (a) and (b) in Figure 7, condition number of $p_J$ is calculated from the initial pose of PATHOS-II in Table 3 to every point by increasing $x$ and $y$ by 0.1 in reachable workspace.

From Figure 7 and 8, the condition number is less than 5 for the most part of workspace. However, the condition numbers increase sharply near workspace boundaries. In x-y plane, reasonable workspace as a haptic device is a circle shape of diameter 12cm. In y-z plane, PATHOS-II is isotropic in reachable workspace of which the length of the major and minor axis are 14cm and 12cm, respectively. In x-z plane, the workspace in which $x$ is larger than 6cm is not available, therefore, the workspace is almost the same as the one in y-z axis.

| Table 3: Initial pose of PATHOS-II |
|---|---|---|---|---|
| $x$ | $y$ | $z$ | $R_x$ | $R_y$ | $R_z$ | $l_o$ |
| 0.0 | 0.0 | 22.5 | 0.0° | 0.0° | 30.0° | 45.0 |

(a)          (b)
172

5. CONCLUSIONS

The proposed haptic device PATHOS-II enables 6-DOF manipulation and 1-DOF gripping and its inverse kinematics was solved using 9 sensors. The workspace was optimized to maximize it under the constraint of link length. The link ratio and initial orientation was used to do this. Another strong point of PATHOS-II is the enhanced isotropic manipulability in most reachable workspace with simple kinematics. This was possible because of its symmetric structure.

The condition number was shown to have similar stiffness in reachable workspace. It is expected that PATHOS-II can be used effectively as a haptic device for manipulating an object in many applications, including outdoor robotics.

7. Acknowledgement

This work was supported by grant No. 2000-2-30200-008-3 from the Basic Research Program of the Korea Science & Engineering Foundation and No. 02-PJ3-PG6-EV04-0003 from the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea.

8. REFERENCES

Algorithms for fitting cylindrical objects to sparse range point clouds for rapid workspace modeling

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ABSTRACT: Current methods for construction site modeling employ large, expensive laser range scanners that produce dense range point clouds of a scene from different perspectives. While useful for many purposes, this approach is not feasible for real-time applications, which would enable automated obstacle avoidance and semi-automated equipment control, and could improve both safety and productivity significantly. This paper presents human-assisted rapid environmental modeling algorithms for construction, and focuses on cylindrical object fitting algorithms. The presented algorithms address construction site material of cylindrical shape. Experiments were conducted to determine: (1) the effect of the ratio of length to diameter of the cylinder to the accuracy of the results, (2) the effect of the angle of view to the accuracy of the results, (3) the minimum number of scanned points required to give adequate modeling accuracy for cylinders of various length to diameter ratios. The results indicate that the proposed algorithms can model geometric primitives used in a construction site rapidly and with sufficient accuracy for automated obstacle avoidance and equipment control functions.

KEYWORDS: CONSTRUCTION AUTOMATION; LASER RANGE FINDER; OBJECT FITTING; OBJECT MATCHING; WORKSPACE MODELING

1. INTRODUCTION

Considerable effort has been devoted to the development of methods of extracting geometrical information from a scene, which is still a major concern for both computer vision and robot vision (Lebegue 1993, Tsukiyama 1996). Determining the dimensions, distance and orientations of planar and curved object surfaces such as walls, doors, pipes and other man-made objects is still a key issue and therefore modeling of the geometric features of a workspace typically demands a large amount of computation due to very large data sets (Tsukiyama 1996). A new method to extract geometric information from a scene by taking advantage of human cognitive skills is under development at the University of Texas at Austin (Cho et al 2002, Kwon et al 2002). A significant advantage of this approach is the ability to extract models of real world objects in a construction workspace from only a limited number of scanned points (less than 50 pts. per object), which are termed sparse point clouds here. Current methods for construction site modeling employ large, expensive laser range scanners that produce dense range point clouds of a scene from different perspectives. While useful for many purposes, this approach is not feasible for real-time applications, which would enable automated obstacle avoidance and semi-automated equipment control, and could improve both safety and productivity significantly (McLaughlin 2002). The dynamic nature of the construction environment requires that a real-time local area modeling system be capable of handling a rapidly changing and uncertain work environment. However, in practice, simple, and reasonably accurate geometric primitives can give a sufficient feedback to an operator, who is controlling an equipment to place objects in an unstructured construction site. For real-time obstacle avoidance, such volumes also facilitate computational tractability.

With regard to the geometric objects most frequently encountered in a workspace, it appears
that a few types of primitives can be used to model a wide range of construction scenes. These are planar objects, cuboids, and cylindrical objects. Particularly, cylindrical objects can be used in plant construction to fit and match chemical pipes, ventilation pipes, and plumbing pipes. This paper presents algorithms that accurately fit and match objects of cylindrical shape, with regard to location and orientation, to sparse point clouds. Experiments were conducted to determine modeling accuracy of the algorithm at the Field Systems and Automation Laboratory of The University of Texas at Austin.

2. THE FITTING METHOD FOR CYLINDRICAL OBJECTS

A single-axis laser range finder, a pan/tilt unit (PTU), and a personal computer were used for the experimental set up. The single-axis laser range finder (DistoMemo) that is mounted on the PTU is designed not only for hand-held operation, but also for computer use through an interface. The measurements can be remotely taken and transferred directly into the computer.

Recent research results indicate that graphical workspace modeling can improve construction equipment control and operations. Equipment operators can use graphical workspace models as an interactive visual feedback tool while controlling equipment (Kim and Haas 2000). For the rapid modeling of construction site objects from sparse point clouds three basic algorithms have been developed that address construction site objects. These are: (1) cuboid fitting algorithm, (2) cylinder fitting algorithm, (3) sphere algorithm, and (4) planar algorithm. This paper focuses on the cylinder fitting algorithm.

Algorithm development and revisions were based on lab experiments. By using these algorithms we achieve: (1) accurate and reliable methods to save computational cost and time, (2) improved fitting algorithms to attain real-time execution, and (3) increased modeling accuracy with operator’s assistance. Figure 1 shows the entire fitting process.

2.1 Solid cylinder fitting algorithm

Four parameters are necessary to define a bounded cylinder: a scalar radius \( r \); an axis vector, \( \mathbf{c} \); a center point to place the axis vector, \( \mathbf{c} = (Xc, Yc, Zc) \); and a length of cylinder that defines the boundary of the cylinder. This algorithm uses the nearest neighbor algorithm to define the normal vector. Four scanned points are used to compute the planar surface of the cylinder. By projecting the points on the curved surface onto the computed planar surface, parameters \( r \) and \( \mathbf{c} \) can be estimated. The radius of the circle is defined as the distance from the center of the circle to any point on the optimized curve. A primary estimation of the radius, \( \hat{r} \), is found by \( \hat{r} = \text{mean} (\| \hat{c} - k \|) \) \( (k = \{ \text{the projected points on the optimized curve of planar surface} \}) \). Consequently the final values of \( a, c, r \) are found by the least squares method using data \( d \).

2.2 Hollow cylinder fitting algorithm

In the hollow cylinder fitting algorithm, Principal Components Analysis (PCA) was used to determine the primary axis of cylinder. Excluding the steps for computing the primary axis, the other steps of the algorithm follow the same sequence as the solid cylinder algorithm.

PCA is a distribution-based ordination method in which the distance between sites in an ordination diagram is correlated with multi dimensional distribution (Duda et al, 2001). PCA assumes that all vectors in a set of \( n \) dimensional samples \( a_1 \ldots a_n \) can be explained by a single vector \( a_0 \). The vector \( a_0 \) is derived using the least squares method, in which the sum of the squared distances between \( a_0 \) and the various \( a_k \) are minimized. We define the square-error criterion function \( F(a_0) \) by

\[
F(a_0) = \sum_{k=1}^{n} \| a_k - a_0 \|^2
\]

\[
p = \frac{1}{n} \sum_{k=1}^{n} a_k
\]

\[
F_0 = \sum_{a_k} \| a_k - p \|^2
\]

Projecting the sample data onto a line through the sample mean, one-dimensional representation can be computed. If we let \( e \) be a unit vector of the line direction, the line equation is

\[
a = p + de
\]

Scalar \( d \) is the distance between the sample data and the sample mean \( p \). We can find the coefficients \( d_k \) by minimizing the squared criterion function.

\[
F_0(d_1, \ldots, d_n, e) = \sum_{k=1}^{n} \| p + d_k e - a_k \|^2
\]

\[
d_k = e' (a_k - p)
\]
The best direction $e$ of the line can be found by solving scatter matrix $U$, which is defined by

$$ U = \sum_{i \in T} (a_i - p)(a_i - p)' $$

(7)

$$ F(e) = -e'Ue + \sum_{i \in T} \|a_i - p\|^2 $$

(8)

LaGrange multipliers can be used to maximize the $etUe$, which is subject to the constraint $||e||=1$. Let $\phi$ be an undetermined multiplier. We can do the differentiation of

$$ v = e'Ue - \phi(e'e - 1) $$

(9)

with regard to $e$ getting

$$ \frac{\partial v}{\partial e} = 2Ue - 2\phi e. $$

(10)

By setting the gradient vector equal to zero, we see that $e$ should be an eigenvector of the scatter matrix. The eigenvector will be the primary axis of the cylinder that can be obtained by reducing the dimensionality of the feature space and by restricting attention to the directions along the scatter of the cloud (Vemuri et al.1986, Vemuri and Aggarwal 1987, Schweikert 1966). It will be the primary axis of the cylinder.

$$ Ue = \phi e $$

(11)

After finding the primary axis of a cylinder, the estimated planar surfaces can be generated on the top and bottom of a hollow cylinder. By projecting the points of the curved surface onto the planar surfaces, the radius and center point of the hollow cylinder can be estimated. The radius of the circle is found using the same method used in the solid cylinder algorithm. Consequently the final values of the radius, length, center point, and primary axis are found by this fitting algorithm using scanned data. Figure 2 shows the scanned points and the computed primary axis of the cylinder. Figure 3 illustrates scanned points and projected points onto planar surface of the cylinder. Figure 4 shows the points projected from the curved surface onto the planar surface of the cylinder. Figure 5 shows modeled cylinders computed by the scanned points from actual objects.

3. EXPERIMENTAL RESULTS

Experiments were conducted to determine: (1) the effect of the ratio of radius to length ($L/D$) of the cylinder to the accuracy of the results, (2) the effect of the angle of view to the accuracy of the results, (3) the minimum number of scanned points required to give adequate modeling accuracy for cylinders of various length to diameter ratios.

Experiments were performed for cylinders with 3-inch through 5-inch radii. For each size of cylinder, several measurements have been conducted. Specifically, measurements based on 10, 20, 30 and 40 scanned points, were conducted for each tested cylindrical object. To increase the accuracy of the experiments, each test has been repeated 30 times. Thus, 120 tests per factor were conducted for the evaluation of the performance of the algorithm in respect to each one of factors (radius, length, and axis). The following results were obtained (Table 1, Figures 6 and 7):

- The relationship between radius and length of the visible section of a cylinder affects the accuracy of the cylinder fitting algorithm
- The most accurate results in radius, length, and axis were obtained for a 90 degree angle of view.

Results of tests using fixed radius (3 to 5-inch), various lengths (range from 10 to 25-inch), and various angles (30, 60, 90 degrees) show that:

- Ten scanned data points give adequately accurate estimates of radius, length, and axis for all tested cylinders.
- Minimal improvement in accuracy is achieved by scanning more than 10 points.

With respect to the accuracy of the estimates of length, both the number of data points and the way scanned data points are distributed on the surface of the cylindrical object play a significant role. In other words, it is of prime importance to select well distributed points on the visible surface of cylinder. Restriction of points only on a small area of the cylinder’s surface results in lower correlations and poorer parameter estimates. In addition, the distance from the object to the laser scanner affects modeling accuracy, precision error, and accuracy error.
4. CONCLUSION

The proposed algorithms for fitting cylindrical objects are computationally efficient and suitable for use in equipment control and obstacle avoidance for safety applications. They are also acceptable for generating construction as-builts, however for long pipe sections they would have to be corrected with pipe end points. These algorithms should be broadly applicable.

5. ACKNOWLEDGEMENTS

This paper is based on the research funded by the National Science Foundation (Grant#: CMS-0000137) and the National Institute Standard and Technology (Project NBR: NA1341-02-W-0742). The authors gratefully acknowledge their financial support and encouragement throughout this study. The authors also appreciate the assistance from Sang-Wook Han, J.K. Aggarwal, and Mohan Sridharan.

6. REFERENCES

McLaughlin, J., “Rapid Human-assisted Creation of Bounding Models for Obstacle Avoidance in Construction” Master's thesis, Department of Mechanical Engineering, University of Texas at Austin, Austin, Texas, 2002


Figure 1. Object Fitting Method

Loop until we get a good modeling is achieved.

Figure 2. Scanned Points Computed Primary Axis

Figure 3. Result of Fitting (1)

Figure 4. Result of Fitting (2)

Figure 5. Modeled Cylinders

Fitting the points by nearest neighbor fitting surface.
Table 1. Summary of Experimental Results of Analysis

<table>
<thead>
<tr>
<th>L/D Approx.</th>
<th>10 pts.</th>
<th>20 pts</th>
<th>30 pts</th>
<th>40 pts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage of Error (%)</td>
<td>Percentage of Error (%)</td>
<td>Percentage of Error (%)</td>
<td>Percentage of Error (%)</td>
</tr>
<tr>
<td></td>
<td>Radius</td>
<td>Length</td>
<td>Devi. of Axis</td>
<td>Radius</td>
</tr>
<tr>
<td>L/D ≈ 1.0</td>
<td>11.50</td>
<td>11.00</td>
<td>14.19</td>
<td>14.50</td>
</tr>
<tr>
<td>L/D ≈ 1.5</td>
<td>4.75</td>
<td>8.67</td>
<td>2.66</td>
<td>3.75</td>
</tr>
<tr>
<td>L/D ≈ 2.0</td>
<td>4.50</td>
<td>5.35</td>
<td>2.58</td>
<td>4.00</td>
</tr>
<tr>
<td>L/D ≈ 2.5</td>
<td>3.00</td>
<td>2.88</td>
<td>1.94</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Figure 6. Percentage of Error for Radius of Cylinder

Figure 7. Percentage of Error for Axis Deviation of Cylinder
Multimodular Complex Riding On Air Cushion Used For Internal Fitting and Finishing Work

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ABSTRACT: Self-Propelled manipulation system which is a mobile robot uses for its movement a chassis, a device on aerostatics supports. The catch of the manipulation system takes its positions at the point of support on the indoors floor and clutches with it. By means of its drives the manipulation system moves chassis into its initial position for fulfilling technological operations. After this, chassis is stabilized in the initial position while the manipulation system is transmitted into its operating position. The use of pantograph in the kinematic scheme of the manipulation system enables to mount the drives on the chassis directly as well considerably to extend the zone of service from one point of support. When using the mobile robot indoors on the chassis having a load weight up one ton the dimensions of operating zone are up to four meters high with indoors area up to thousand square meters.

KEYWORDS: manipulation system, mobile robots, aerostatics supports, construction, kinematics.

1. INTRODUCTION

Some process like those involved in fitting, finishing and auxiliary work in housing and industrial construction are both labour intensive and difficult to automate, among them numerous hauling operations concerned with moving materials and tools over a construction site. Yet, they need to be calculated against time since contemporary fitting and finishing operations demand that motional functions be performed accurately and effectively.

A robot-based area designed to provide for accurate manipulation of diverse equipment and for extensive handling schemes could significantly reduce the labour input and hence, increase profitability of operations. Multi-modular structure of major function subsystem in the area and a hierarchical control and intelligent system could do the job, the structural elements being a hovercraft (HC), a multifunctional manipulation system (MS) and a navigation system ensuring adequate accuracy of all handling operations all over the construction site.

2. THEORY AND EXPERIMENT

Processes taking place in the automated construction site impose certain requirements on the robot motive capabilities. These requirements can be met by including in the structure of the manipulation system of an adequate number of axes. In accordance with the classification accepted in robotics, there are the following groups of joint motions:

- global motion – within the entire area of the construction site;
- regional motion – displacement of a gripping device within the workspace determined by the length of the manipulator chain links;
- small displacements of manipulator end link in a limited area of workspace.

In accordance with this classification, the overall structure of manipulator can be broken down into kinematic sections which perform various functions.

Robot must be mobile, i.e. able to move around the worksite. Global motion are to be generated by a vehicle riding on an air cushion and in addition, provide for the vehicle orientation with respect to the coordinates set by the benchmarks fixed on the territory of the worksite.

The above considerations allow us to design a conceptional manipulation system of an automatic programmable mobile robot to use it on a 1,000...
m² worksite up to 4 m high. When conceiving a MS structure, one should strive to keep the number of axes minimal but sufficient (W=6) and to choose cylindrical coordinates as ensuring a simpler way of motion programming. The conceptional MS model and its kinematics are shown in fig.1.

The axes serve the following purposes: q1 - replacement of the manipulator arm from transport position to a working position; q2 - arm rotation to get a working instrument to more along the longitudinal axis of a benchmark; q3, q4 - coordinate displacement of working instrument along vertical and lateral axes of benchmark; q5, q6 - hand rotation ensuring that the axes of the working instrument is perpendicular to the surface to be worked.

Linear translation of working instrument in MS can be performed by a pantograph mechanism, which can ensure linear dependence between coordinate hand displacements and internal coordinates q3 and q4 by means of slow speed drivers fixed at the base of manipulator. Let us look at the pantograph mechanism shown in fig.2.

The design of this manipulation system, when mounted on a hovercraft, allows travel relative to global generalized coordinates. In this case the structure will be rigidly attached at point H to the benchmarks on the area, while by means of MS and HC drivers it can move over the entire area of the construction site.

Figure 1. Kinematic structure of robot manipulation system

After MS is installed in a predetermined position, MS is brought into working position to perform fitting and finishing operations.

This mechanism consists of three loops OABDO, OACEDO and OACHO. In a complex form, the loop closing equations can be written as

\[ y + l_{11} \cdot e^{\alpha_{11}} + l_{21} \cdot e^{\alpha_{21}} - i \cdot z = 0; \]
\[ y + l_{11} \cdot e^{\alpha_{11}} + l_{21} \cdot e^{\alpha_{21}} + (l_{11} - l_{11}) \cdot e^{\alpha_{11}} - i \cdot z = 0; \]
\[ y + l_{11} \cdot e^{\alpha_{11}} + l_{21} \cdot e^{\alpha_{21}} - H_y = 0, \] (1)

where \( y \) and \( z \) are displacements generated by independent motors along axes OX and OZ respectively. Real parts of equations (1) can be written as

\[ y + l_{11} \cdot \cos \alpha_{11} + l_{21} \cdot \cos \alpha_{21} = 0; \]
\[ y + l_{11} \cdot \cos \alpha_{11} + l_{21} \cdot \cos \alpha_{21} - H_y = 0, \] (2)

imaginary parts can be written as

\[ l_{11} \cdot \sin \alpha_{11} + l_{21} \cdot \sin \alpha_{21} - z = 0; \]
\[ l_{11} \cdot \sin \alpha_{11} + l_{21} \cdot \sin \alpha_{21} - H_z = 0, \] (3)

where \( H_y \) and \( H_z \) are orthogonal components describing displacements of the wrist. Let us introduce link length ratios \( k_1 \), and \( k_2 \) which we shall call amplification factor

\[ k_1 = \frac{l_{11}}{l_{21}} = \frac{l_{21}}{l_{22}}; \] (4)

Figure 2. Pantograph mechanism
Amplification factor $k_1$ is a ratio of corresponding sides of similar triangles ADB and AHC. The mechanism will evidently be a pantograph if quadrangle BCED is a parallelogram and points A,B and H are in line. The relation between $k_1$ and $k_2$ can be defined from the relationship:

$$
\frac{DB}{BC} = \frac{l_{12}}{l_{11} - l_{11}} = \frac{k_2}{k_1 - 1}.
$$

After introducing amplification factor $k_1$ into equations (2) and (3) a little manipulation yields:

$$
H_y = (1 - k_1) \cdot y;
$$
$$
H_z = k_1 \cdot z. \tag{7}
$$

Time differentiation of equation(7) yields relationships for speeds and accelerations:

$$
H'_y = (1 - k_1) \cdot y';
$$
$$
H'_z = k_1 \cdot z'; \tag{8}
$$
$$
H''_y = (1 - k_1) \cdot y'';
$$
$$
H''_z = k_1 \cdot z''. \tag{9}
$$

Pantograph mechanism used in manipulator appears to produce linear dependencies between input and output displacements, speeds and accelerations along each coordinate. In addition, this mechanism can be considered as a linear displacement amplifier with two amplification factors: $(1-k_1)$ for $y$-axis and $k_1$ for $z$-axis. The pantograph mechanism is based on a parallelogram. The ends of its four links are connected by kinematic turning pair in such a way that the pivot axes are perpendicular to the motion plane. This mechanism used for motion transmission permits higher rigidity of MS if relationships of mobile link lengths of the pantograph mechanism are chosen correctly. Like the links of the quadrangle, the other manipulator links experience tensile – compressive load and hence, are bend resistant, which is linearly dependent on the mass-to-length ratio. This ratio can be significantly reduced by employing an off-loaded' MS with the drives brought out to the base of the manipulator. All above shows that pantograph mechanism can successfully be used when dealing with fitting and finishing operations.

The systems of robot manipulation, information-processing and control used in fitting and finishing operations in building and industrial construction (fig.3) include:


Figure 3. Functional diagram of robot control system

D.C. separately exited motor can be employed as a power generating unit of the manipulation system (1,2). Angular velocity of the motor is reduced by means of a reduction gear, and rotary motion is converted into transnational motion with required speed by means of screw-and-nut gearing (9,10). Control over the path-following motion is performed using optoelectronic vertical and horizontal positioning transducers (3,4). Developed using from a photon-coupled pair. “light-emitting diode–photodiode and disk-slit diaphragm mounted on the input shaft of the reduction gear. Control over the direction of joint motion is performed using analogue permanent magnet-field tachometers(5,6) with output tension of positive or negative polarity, depending on the rotational direction. The shafts of tachometers and motors are connected through belt transmission. Limit switches (7,8) are used as end-position pickups which also perform as switch-off protection devices. MS actuators can be controlled by pulse-duration modulation of computer signal.
Global travel is affected by a hovercraft. A hovercraft has several advantages over conventional vehicles employed at construction sites. They are:

1. Low tractive resistance; material handling by a hovercraft requires much less tractive force than by wheel or clawer-belt transport;
2. Better maneuverability in a horizontal plane; a hovercraft provides motion and turn in any direction as well as rotation about its axis.
3. Better load-carrying capacity;
4. Low pressure brought to bear on support surface, which leads to reduced floor wear and hence, its increased durability;
5. Simplicity of design and relatively low manufacturing cost, which allows capital costs to be cut down.
6. Low cost of service, because hovercraft operation does not require specially trained personnel.

3. STATEMENT

The purpose of this development is to increase efficiency and safety of fitting and finishing operations on the construction. To achieve this goal, one has to approach the following problems:

- to identify key requirements and principles of robotization of fitting and finishing processes;
- to conceive a model of the MS, determine its parameters and study its kinematics characteristics;
- to develop the algorithms of control of robot motions and principles of building an adequate navigation system;
- to study drive dynamics of major axes and adaptability of axes motion under changing mass-inertia characteristics of robot manipulation system;
- to materialize model algorithms and produce recommendations on their practical application.

4. REFERENCES

ABSTRACT: For safe and efficient execution using the microtunneling method, it is necessary to understand both buried objects and ground information. The authors adopted an electromagnetic wave sensing system, devised an antenna that can be installed in a microtunneling driving machine with a diameter of approximately ø350 mm, and incorporated an original analysis algorithm to develop a frontward sensing system capable of automatically judging the locations of buried objects. This system made it possible to accurately detect both the presence and distance to buried objects to the front and sides of the driving machine, thus improving driving safety and efficiency.

Keywords: frontward sensing, radar, utility detection, electromagnetic wave, microtunneling

1. INTRODUCTION

NTT independently developed and marketed the ‘ACEMOLE’ as a technology for laying electronic communications conduits. The applications of this method have expanded from communications conduit laying to take in installation of underground lifeline such as sewage and water supply pipes and electric cables, and the method has now been used to lay in excess of 700km of pipe and conduit. For safe and efficient execution using the microtunneling method, it is necessary to understand both buried objects and ground information. Thus far these investigations have consisted of advance test boring, checking past facility records and drawings, and using equipment for detecting buried objects from above ground. However, these methods have various problems such as discontinuous data and insufficient or unclear data that required follow-up surveys, etc. Therefore, various frontward sensing techniques which detect buried objects by transmitting and receiving elastic waves and ultrasonic waves from antennas or other devices installed in the driving machine have been proposed to solve these problems, and some of these have been applied in the field. However, these technologies were designed for large-bore shield machines, and application to the microtunneling method faces problems such as limits to installation in driving machines and drops in recognition performance due to reduced device sizes. Determining the presence and location of buried objects from the detection data also requires experience and skill, so application is still impractical. Therefore, the authors adopted an electromagnetic wave sensing system, and devised an antenna that can be installed in a microtunneling driving machine with a diameter of approximately ø300 mm. An original analysis algorithm for the data obtained from this antenna was also incorporated to develop a frontward sensing system capable of automatically judging the locations of buried objects. This system made it possible to accurately detect both the presence and distance to buried objects to the front and sides of the driving machine.

2. FRONTWARD SENSING RADER SYSTEM

The developed frontward sensing radar system is comprised of a radar antenna unit that senses buried objects and a main unit that processes and displays the signals received from the antenna. (Fig. 1)
Operators perform driving work while watching the image appearing in the display. In addition, the main unit incorporates an algorithm as described in section 2.3, and is equipped with a function that automatically stops driving when the antenna senses a buried object. This prevents collisions with buried objects and other accidents.

### 2.1 Antenna Characteristics

Fig. 2 shows the receiving antenna and transmitting antenna appearance. The antenna elements have teardrop shapes, with the receiving antennas positioned at the top and bottom and the transmitting antenna in the middle. Compact antennas were newly developed to achieve a size capable of mounting in the front of a driving machine. This made it possible to install the antenna in a driving machine with a diameter of approximately ø350 mm. Note that this antenna has a sensing range of 1.5 m in the frontward direction and 1.2 m in the lateral direction. (Fig. 3)

### 2.2 Antenna Configuration

The conventional frontward sensing system shown in Fig. 4 could only judge the presence of buried objects, and was incapable of determining the distance to, direction and location of buried objects. Therefore, this new system measures the radio waves from the transmitting antenna with multiple receiving antennas, making it possible to determine the distance to, direction and location of buried objects. Two receiving antennas with offset directional angles are positioned as shown in Fig. 5 so that the upper antenna receives the reflected waves from directly in front and upward, and the lower antenna receives the reflected waves from directly in front and downward. This means that when only the upper antenna catches strong reflected waves, a buried object is present at a front and upward location, and when only the lower antenna catches strong reflected waves, a buried object is present at a front and downward location. Also, when both the upper and lower antennas receive a reflected wave at the same time, a buried object is present in the driving direction. The distance to the buried object is determined by the location judging algorithm described in the following section.
2.3 Location Judging Algorithm

Fig. 6 shows the algorithm for judging the location of buried objects while driving.

First, the image data from the antenna unit incorporated into the driving machine is obtained online while driving (Fig. 7). Next, average difference processing is performed to eliminate continuous linear reflection in the horizontal direction. (Fig. 8)
Then, signals with a reflection strength of a threshold value or higher are extracted from the image remaining after the average difference processing. (Fig. 9) At this time, only the straight lines that satisfy equation (1) are extracted.

\[ AX + B(A \neq 0) \]  

Next, the distance between both endpoints of the extracted lines and the round-trip propagation time of each endpoint are calculated. This distance and round-trip propagation time are then substituted into equation (2) to calculate the distance \( L \) to the obstacle.

\[ L = \frac{cT}{2\sqrt{\varepsilon}} \]  

Note that \( T \) is the round-trip propagation time, \( c \) is the speed of light (\( 3 \times 10^8 \) m/s), and \( \varepsilon \) is the dielectric constant which is unique and differs according to the soil quality. The direction, distance and other information concerning the detected buried object are displayed on the screen. Thus, the possibility of a collision is judged from the position information searched for. When there is the possibility of a collision, a machine is stopped automatically.

3. FUNCTION TESTS

Basic tests were conducted both above ground and underground using the developed antennas.

3.1 Basic Above-ground Test

This test observed changes in the data due to the antenna's advance, and aimed to investigate the beam angle from the transmitting antenna and the sensing range. As shown in Fig. 10, steel pipes for measurement was placed in a wooden pipe position adjustment frame that allowed the pipe position to be adjusted at 10 cm intervals in the vertical direction. The distance between the antenna and the pipe was then changed, data was obtained, and the angle of antenna beam travel was investigated.

3.2 Above-ground Test Verification Results

Fig. 11 shows the changes in the center position of the beam. This verification used a steel pipe with a diameter of ø100 mm. The results showed that the angle of antenna beam travel changed with an inclination of approximately 45°.

3.3 Basic Underground Test

A test soil tank was created with multiple buried pipes (Fig. 12). The reflection characteristics for four buried pipe depths and five patterns of pipe type (steel pipe, vinyl pipe) and pipe inclination
were investigated with backfill soil conditions of sandy soil and Kanto loam. Data was obtained by placing the antenna in the center of the buried pipe and scanning in the perpendicular direction, and the attenuation characteristics of the electromagnetic waves were investigated.

3.4 Underground Test Verification Results

Fig. 13 shows the results of verifying the attenuation characteristics of the electromagnetic waves. The investigation used data with a fixed gain. As shown by the slopes in the graph, Kanto loam exhibits a greater amount of attenuation than for sandy soil. Also, based on the gain size and the slope for steel pipes at a depth of 0.5 m, the estimated gain at a depth of 0 m is 35.5 dB for sandy soil and 20.5 dB for Kanto loam. This indicates that the reflection is greater when waves are emitted from the antenna into sandy soil than when emitted into Kanto loam. The vinyl pipes showed smaller reflection than steel pipes in both soil qualities, indicating that they have a larger gain. The amount of attenuation in each soil quality is thought not to change according to the pipe type. Based on these results, sensing vinyl pipes at a depth of 1.5 m requires a gain of 98.5 dB or more in sandy soil, and 91.5 dB or more in Kanto loam. This radar system has a gain capability of 100 dB or more, so it can be applied to these soil qualities.

**Figure 12. Underground pipe arrangement**

**Figure 13. Attenuation characteristics of electromagnetic waves**
4. CONCLUSION AND FUTURE PLANS

This paper reported the effectiveness of frontward sensing technology using electromagnetic waves for the microtunneling method. In addition to a newly developed antenna, this system also applied a judgment algorithm to the obtained data to allow automatic judgment of the locations and distance to buried objects.

In the future, driving machine tip materials and man-machine interfaces will be investigated in order to mount the antenna in an actual driving machine. In addition, there are also plans to conduct on-site verification with actual driving machines to further raise the degree of system completeness.

5. REFERENCES

[Miyaratake, Baba, Hara, Sudo and Nagashima] “New ESPAR, the underground radar with great performance and estimation of prospect for NO-DiG investigation in Japan,” 18th International Conference on NO-DiG 2000, Perth AUSTRALIA, 2000,


Development Of Hybrid Robot
For Construction Works With Pneumatic Actuator

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ABSTRACT: This paper presents a construction robot that is a hybrid type robot using pneumatic actuator. The hybrid type robot can be used in a window glass mounting, panel fixing, engine installing by gripper changing and so on. We proposed a mechanism of hybrid type robot for construction works, derived a kinematic modeling and simulated to be convinced of a propriety of its mechanism. The hybrid type robot mechanism has a wide range of workspace and precision and consists of a serial and parallel part. The developed hybrid robot has a large workspace and high strength-to-moving-weight ratio at the same time. The pneumatic actuator has been used in industry site. This is largely due to their inherent ability to provide low-cost, compact, and safe actuation. These abilities are good properties for developing robot for a construction site, such as low cost, the high rate of power/weight, usability, and simple structure. The restricting factors preventing a wider use arise from highly nonlinear dynamic properties such as air compressibility and friction effects, which combine to severely degrade responsibility and positional accuracy. The sliding mode controller is adequate to such as cylinder that is strong nonlinear property.

KEYWORDS: Construction robot, Hybrid robot, Parallel mechanism, Pneumatic Actuator, Sliding control.

1. INTRODUCTION

Recently, the robot is widely used in various fields, and is used not only in formal factory line but also in outdoor place. A construction robot is developed to help human worker in construction site. In a field of construction work, the content of work and working material are frequently changeable. And Construction worker and robot work in same place. So construction robot needs several special properties of high payload, safety, reliability, and a wide workspace. [L.H.Y] The characteristics of a hybrid type robot satisfy these needs, because the hybrid type robot has a wide workspace and high payload capable and high-precision. The hybrid type robot in this study consists of a serial and parallel part. The serial part has a wide workspace and low payload. The parallel part has high precision, a narrow workspace, and high payload capability. [Ming Z. Huang] Lee and Shah presented the kinematical structure of the 3RPS parallel manipulator and analyzed this mechanical structure.[Lee and Shah] Huang, Ling and Yang studied the characteristics of parallel-serial hybrid manipulators [Ming Z. Huang].

A pneumatic actuator has the advantages of durability, high payload-to-weight and payload-to-volume ratios, high speed and force capabilities, and a variety of power transmission methods based on a simple operational mechanism. [S. R. Pandian][H. Janocha] The environment in a field of construction work is dirty, dangerous, variety. As a result, the pneumatic actuator apply to a construction robot. However, the restricting factors preventing a wider use arise from highly nonlinear dynamic properties such as air compressibility and friction effects which combine to positional accuracy. [R. Richardson] These nonlinear dynamic properties make difficult to control pneumatic actuator. Many control algorithms are suggested for many years to control the pneumatic actuator. Junbo song and Yoshihisa ishida performed a robust sliding mode control on friction factor.[JSong and Y. Ishida] Robert, Brown and Plummer demonstrate self-tuning control
algorithm for a low-friction pneumatic actuator under the influence of gravity [R. Richardson].

In this study, we develop the construction robot for supporting the human worker at the field of attaching heavy ceramic tile on wall. The designed robot lift and support heavy ceramic tile while human worker attach a tile on a wall. The worker can easily control the robot end-effector position with MMI (Man Machine Interface).

The mechanism design and system schematic are present in Sec.2. The sliding controller is mentioned in Sec. 3. In Sec 4, we show the experiment result.

2. MECHANISM DESIGN & ANALYSIS

2.1 Mechanical Structure

To use a construction robot in the environment of a wide workspace and high weight, the 6 DOF robot consisting of a PRRR serial structure and 3RPS parallel structure was developed in this study. The developed robot is shown as Figure 1.

Figure 1. Serial-parallel hybrid type robot model

Using the pneumatic actuators at the serial axis 3 and the parallel part, the robot is developed to absorb the effect of the impact and the disturbance of external forces.

A parallel part is the 3RPS structure suggested by Lee and Shah [Lee and Shah]. The structure of the parallel part has three revolute joints at a fixed base and three ball joints at a moving platform, so it has 2 revolute motions and 1 prismatic motion. Figure 2 shows the parallel part of the developed robot.

Figure 2. Parallel part of the developed robot

2.2 Kinematic Analysis

2.2.1 Forward Kinematics

The serial part has 4DOF in Figure 1 and the parallel part in Figure 2 has 3DOF. In this system, a parallel workspace is narrow and small as shown in Figure 3 because of the interference of each link in the parallel robot.

Figure 3. Workspace of the parallel part

As the workspace is very narrow at the Y-Z plane, the parallel part with the constraint of Z axis can be considered as 2 DOF (i.e. 2 rotational motions). Therefore, this hybrid type robot is regarded as a 6 DOF serial robot. Table 1 shows the Denavit-Hartenberg parameters.
The positioning motion part with the serial axes 1, 2 and 3 determines the desired position. The orienting motion part with the serial axis 4 and the parallel part determines the desired orientation. (Figure 4)

![Figure 4. Kinematic analysis of the developed robot](image)

**Table 1. Denavit-Hartenberg Parameters**

<table>
<thead>
<tr>
<th>i</th>
<th>(\alpha_{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>(d)</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>(L_1)</td>
<td>(\theta_2)</td>
</tr>
<tr>
<td>3</td>
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<td>(L_3)</td>
<td>0</td>
<td>(\theta_3)</td>
</tr>
<tr>
<td>4</td>
<td>(90^\circ)</td>
<td>(-L_3)</td>
<td>(L)</td>
<td>(\theta_4)</td>
</tr>
<tr>
<td>5</td>
<td>(-90^\circ)</td>
<td>0</td>
<td>0</td>
<td>(\theta_5)</td>
</tr>
<tr>
<td>6</td>
<td>(-90^\circ)</td>
<td>0</td>
<td>0</td>
<td>(\theta_6)</td>
</tr>
</tbody>
</table>

**2.2.2 Inverse Kinematics**

When a point in base coordinates \((x, y, z)\) is given, we obtain the following Eq. (1) using Table 1

\[
^0^T^3P = \begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} \begin{bmatrix} -L_3 \\ 0 \\ 1 \end{bmatrix}
\]

(1)

From Eq. (1), \(d_i\), \(\theta_2\) and \(\theta_3\) are as follows:

\[
\theta_2 = A \tan 2(p_y, p_x) \\
a = p_x c_2 + p_y s_2 - L_3 \\
\theta_3 = A \tan 2(-L_4, L_5) + A \tan 2(L_4^2 + L_5^2 + a^2, -a)
\]

(2)  
(3)  

When a rotation matrix \(^0R\) is given, \(^3R\) obtained from \(^0R\) using Eq.s (2), (4) and (5) is as follows:

\[
^3R = \left( ^3R \right)^T \cdot ^0R
\]

(6)

From Table 1, \(^3R\) is as follows:

\[
^3R = ^3R_1^3R_2^3R_3^3R_4^3R_5^3R_6
\]

(7)

Using Eq. (6) and Eq. (7), \(\theta_i\), \(\theta_k\) and \(\theta_e\) are as follows:

\[
\theta_k = ^4R(2,1) \\
\theta_e = a \sin \left( -\frac{^3R(2,2)}{c_5} \right) \\
\theta_e = a \tan \left( ^3R(3,1), ^3R(1,1) \right)
\]

(8)  
(9)  
(10)

Using a rotation matrix of parallel manipulator from \(\theta_k\) and \(\theta_e\), parallel link lengths are determined.

**2.2.3 Dynamic Analysis**

To obtain robot dynamic equation, the robot mechanical system is considered and shown in Figure. 6 (a). If the parallel part is simplified to a lumped mass, the kinetic energy of the robot can be described by the following Eq. (11).

\[
k_i = \frac{1}{2} m_i v_i^T \dot{v_i} + u_i + \sum_{i=1}^{3} k_i
\]

(11)

The potential energy is as follows.

\[
u_i = -m_i g \cdot \dot{v_i}^T \dot{v_i} + u_i, \quad u = \sum_{i=1}^{3} u_i
\]

(12)

From Eq.s (11) and (12), the dynamic formulation becomes:

\[
\tau_i = \frac{d}{dt} \frac{\partial k_i}{\partial \dot{\theta}_i} + \frac{\partial k_i}{\partial \dot{\theta}_i} + \frac{\partial u}{\partial \dot{\theta}_i}
\]

(13)

Therefore, the torque of the serial axis 3, \(\tau_i\), is as follows:
\begin{equation}
\tau_3 = \tau_a(\ddot{a}, \theta) + \tau_b(\dot{\theta}^2, \theta) + \tau_c(\dot{\theta}, g) + \tau_g(g, \theta)
\end{equation}

where,
\begin{align*}
\tau_a & : \text{torque by the acceleration}, \ddot{a} \\
\tau_b & : \text{torque by the angular velocity}, \dot{\theta} \\
\tau_c & : \text{torque by the angular acceleration}, \dot{\theta} \\
\tau_g & : \text{torque by the gravity acceleration}, g
\end{align*}

The external force by \( \tau_3 \) is as follows:
\begin{equation}
F = \frac{\tau_3}{a \cos \theta}
\end{equation}

When the end-effector draws a circular path 5cm in diameter for 5 seconds, \( F \) is shown in Figure 5(b).

\[ M \frac{d^2y}{dt^2} + F(y) + f(M, \dot{y}, y) + d(t) = U(t) \]

where,
\begin{align*}
d(t) & : \text{disturbance} \\
U(t) & : \text{control input} \\
F(y) & : \text{external force obtained from eq.(15)} \\
M & : \text{mass} \\
f(M, \dot{y}, y) & : \text{friction force} \\
y & : \text{length of piston}
\end{align*}

This dynamic equation has several nonlinear properties consisting of unknown model parameters, friction force and disturbances. As the linear control method has difficulties, the nonlinear control scheme should be needed.

\begin{figure}[ht]
\centering
\includegraphics[width=\textwidth]{figure6}
\caption{Schematic of pneumatic system (serial axis 3)}
\end{figure}

### 3.2 Sliding Mode Controller

For nonlinear controller, the following uncertain bounds for the pneumatic servo system are assumed as Eq. (17),
\begin{align}
q_1 < Q < q_2 & , \quad Q = M^3 \\
|f(M, \dot{y}, y)| & \leq f_f |\dot{y}| + f_p |y| + f_s \\
|d(t)| & \leq \rho = \text{const}
\end{align}

where,
\begin{align*}
f_f & : \text{damping coefficient} \\
f_p & : \text{stiffness} \\
f_s & : \text{stiction coefficient} \\
q_1, q_2, \rho & : \text{positive constants}
\end{align*}

The Lyapunov function is as follows:
\begin{align}
V & = \frac{1}{2} s^2 \\
\dot{V} & = ss(ce) < 0
\end{align}

\( U(t) \), sliding mode control input, should be satisfied Eq. (19). Therefore, \( U(t) \) is as follows:
\[ U(t) = -\frac{1}{q_i} w(t) + F(y) \]  
\[ w(t) = |a_{n1} y_n| + |a_{n2} \dot{y}_n| + |b_n r| + q_i|\varphi| + c_i|\varepsilon| + q_i (f_f |y| + f_f |\varepsilon|) \]

where,

- \( w(t) \) : reference model parameter
- \( r \) : reference input
- \( y_n \) : reference model state variable
- \( \varepsilon = y - y_n \)
- \( s = c_i \varepsilon + \dot{\varepsilon} \) : sliding surface
- \( c_i \) : positive constant

The objective of the sliding mode controller is that the tracking error between the plant and reference model can be guaranteed within any neighborhood of the boundary layer as time \( \to \infty \). The external force and the bounded uncertainties of unknown model parameters, disturbance and friction force were applied to the control.

### 4. EXPERIMENTAL RESULTS

#### 4.1 The Results of Cylinder Response

Experiments of pneumatic cylinder at the serial axis 3 were performed on a 5kg payload and a free load. In addition, the control considering the external force, \( F \), was compared to the control without considering \( F \).

Figure 7. Step position response of the serial axis 3

Figure 7 shows the step position response of the cylinder in serial part axis 3. The piston starts from the origin to the position of 100mm, 180mm and 40mm for 10 seconds. The control with the external force \( F \) has smaller magnitude of position error than the control without \( F \).

#### 4.2 The Circular Path Tracking Experiment of End-Effector

To test the robot for lifting and moving heavy tile, the robot end-effector position was suspended at commanded point (z-axis :30cm, x,y:0 ) with the tile, and we made motion that is circle path in diameter 5cm. The tile weight was 5Kg, and it was attached on the end-effector with a vacuum pad.

Figure. 8 shows the tracking response of the pneumatic actuator at the serial axis 3. Figure. 9 shows the circular trajectory of the end-effector. The error of the end-effector was generated mostly from the pneumatic actuators, especially the serial axis 3. Therefore, the number of the pneumatic actuators to absorb the effect of the impact should be limited.

Figure 8. Suspending of end-effector position

Figure 9. End-effector path control
5. CONCLUSION

In this paper, the hybrid type construction robot using pneumatic actuator and servo motor was developed to support the human worker for a work of tile or panel material in construction field.

The hybrid type robot has a large workspace and a resistance to a payload. The pneumatic actuators were controlled by the sliding mode controller. The robot dynamics and the nonlinear properties of pneumatic actuator were applied for the sliding mode controller.

In experiment, the proposed construction robot lifts the tile (5kg) and moves it through the circle path. The designed sliding controller is adequate for a pneumatic cylinder control. (Figure 10, 11)

A position resolution of the designed robot system is less than 3mm. It is not high precision level, but this robot system can be used for supporting human worker in some construction works that are not needed high precision.

6. ACKNOWLEDGEMENTS

This work has been sponsored by Samsung Corp., Construction Equipment R&D Part.

7. REFERENCE


Integral Automatic Control System for Premixed Concrete Production Companies (Dosat_H04)

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ABSTRACT: DOSAT H04 is an integral automatic control system for the production and sales management of premixed concrete in cyclical operation gravimetric plants. This system is a tool that guarantees to obtain an stable quality in the production of premixed concrete, and also to control the material resources and invoicing issues of the company. The system is implemented on a PC with Windows98, Windows Me, Windows NT 4.0, Windows 2000 or Windows XP using a TCP/IP protocol for data transmission.

DOSAT H04 is modularly designed so that it can be installed in companies with one plant or more than one plant, covering from the placing of the order, the automatic control of concrete production, inventory control of raw materials, transportation, up to the invoicing to the client.

In the case of companies with more than one plant the system includes:

- Weighing system: formed by string gates, manual control desk, and measuring terminal.
- PC and control software: the computing system presents an intuitive and easy to handle graphic interface that allows to introduce an unlimited amount of recipes, and strong and efficient control program with three types of controllers including a PID, compensation of humidity, etc.
- Global Orders Module: this software attends the creation of contracts of Global Orders that are to be sent to the production plants or to the dispatcher via e-mail, internet, intranet, floppies, etc.
- Daily Orders Module: this software was designed for companies with a dispatcher who divides Global Orders into Daily Orders and distributes them among the different Plants according to their geographical location, production capacity, etc.
- Reporting and Invoicing Module: this software receives information from the different plants and issue more than 90 reports itemized as Production Process Reports, Raw Material Reports, General Transportation Reports, and Client Invoicing Reports.

For companies with only one plant:

In this case the software of control undertakes the functions of the other programs, thus providing all the necessary reports, including the client invoicing information.

Since 1998, with this system 18 plants have been installed in Cuba obtaining the following advantages:

- Quality stabilization of concrete production
- A more rational use of labor
- Reduction in human errors
- Increase in the production rate of the plant
- Increase of operation hours between maintenance stops
- A more strict control of the resources
- Reliable and up-to-date invoicing of the concrete production

KEYWORDS: DOSAT_H04.
1. INTRODUCTION

Dosat_H04 was designed to satisfy the need in Cuban concrete production companies of a reliable tool that allows the automation of the production process, an strict control of material resources and also to carry out the billing to the clients. Consequently the fundamental objectives of the system described in this work are:

- To keep a digital register of the global orders placed by the clients.
- To assure that during concrete production the mixture is prepared using the exact amount of each component (arids, cement, water, and additives) as it is specified in the recipe.
- To guarantee a stable quality of the concrete produced in the plant during its entire useful life.
- To minimize human errors that may occur during the manufacturing process.
- To have reliable information at any moment about material resources as well as of the production of the company.
- To carry out the invoicing to the clients.

2. COMPONENTS OF THE SYSTEM

This system is formed by 4 interrelated subsystems covering from the placing of the concrete order by the client, the computer control of the concrete production process, to the final invoicing to the client. The subsystems are: Global Orders Module, Daily Orders Module, Control of Process Module and Reporting and Invoicing Module.

2.1 GLOBAL ORDERS MODULE

This software is usually installed in the sales department of the company and it is devoted to attend the creation of global concrete contract orders, and to keep databases of clients, building works, etc. After the general orders are created, the program sends the information to the computer where the Daily Orders Module is installed if the company has more than one plant, or to the Process Control Module if there is only one plant. This transmission is carried out through the TCP/IP protocol and that's why the computers must be interconnected in a net like a LAN, intranet, Internet, etc.

2.2 DAILY ORDERS MODULE

As it was previously mentioned, this program is used only in companies with more than one plant and it is in charge of receiving the general orders, divide them in suborders that will be transmitted daily (by TCP/IP) to the different plants, according to their geographical location and capacity of production. It possesses the same databases as the Global Orders Module and also a database of the different plants.

2.3 CONTROL OF PROCESS MODULE

This subsystem is in turn divided in 3 fundamental parts:

- Weighing system
- Manual control desk
- Controlling computer

2.3.1 WEIGHING SYSTEM

It is formed by string gates for measuring the weights in each scale of the plant (See Figure 1) and by the measuring terminal which determines the weight properly said, by measuring the resistance variations of the cells. It has a digital indicator to show the weight in the manual control desk and also communicates with the controlling computer, via a transmission series cable RS232, to send the amount of the weight in each instant (See figure 2).

Figure 1. String gates.

Figure 2. Measuring Terminal.
2.3.2 MANUAL CONTROL DESK

It is a steel desk that contains the previously mentioned measuring terminals and other electric components to operate the plant. In its surface are installed the digital indicators of weight in each scale, and the push-button that handle each component of the plant. As its name indicates, it allows the operator to run the plant manually, without the need of using the controlling computer. Its use is anticipated only for emergencies, when the controlling computer is out of order (See Fig. 3).

Figure 3. Manual Control Desk.

2.3.3 CONTROLLING COMPUTER

It is a regular personal computer, to which some electronic interfaces are added for measuring different variables of the production process and to operate the elements of the plant. The Control Program is installed in this computer (See Fig. 4).

Technical characteristics of the Control Program:
This software is implemented on a PC to operate under Windows98, Windows Me, WINDOWS NT 4.0, Windows 2000 or Windows XP and the data transmission is carried out by means of TCP/IP protocol. It is designed to be configured according to the structure and the requirements of the plant where it will finally function.

Main configurable parameters:
- Name of the plant.
- Volume of each cycle in m³ (capacity of the plant).
- Amount of elements of the plant (arids hopper, cement silos, etc.).
- Whether or not the plant has an independent scale for cement.
- Whether or not the discharge of the materials is carried out automatically after the weighing process or by a command of the operator.
- Whether or not the plant has a mixer installed.
- Whether or not compensation among cycles is wanted.
- Whether or not additives are used.
- In case of using additives, whether the scale is independent or it shares the one for the water.
- Whether or not the plant has vibrators.
- Type of arids transportation.

Given its open architecture, the equipment can accept humidity sensors in arids and of temperature in cements.

It also has a set of interrelated databases that allows to process different types of economic and administrative information of the company.

Databases:
- Clients
- Building works
- Orders
- Suppliers
- Recipes
- Materials
- Trucks
- Truck drivers
- Materials movements: In or out from the plant
- Manual loading: Information of manual dosages in the plant
- Invoicing: Information about the dispatching of concrete to the clients

It generates different reports that the operator can select. These reports are classified in three groups:
• Production reports: They offer all the information about the process of production like summaries of dosages, production general reports, manual operations, eventualities, etc.

• Raw materials reports: They offer information about the movement of materials and their indicators

• Transportation reports: They offer different information about the transportation of concrete; that is to say, general transportation activity, truck activities, transported volume, traveled distances, etc.

Characteristics of Operation:
• Independent control of up to 6 scales. The operational cycle of each scale is independent from the others.

• Automatic linkage of the cycles. The working cycles are automatically concatenated according to the concrete volumes to be processed.

• Capacity to store a limitless amount of recipes.

• Control of users by passwords for changing the configuration of the system. In this way it is assured that only the authorized personnel can change the configuration parameters.

• Automatic calculation of the amount of cycles. The amount of cycles are calculated according to the concrete demand and the capacity of the plant. This information is indicated in the frontal panel interface together with the number of the cycles that is currently under process.

• Auto tare. The weight of each scale at the beginning of a cycle is considered when determining the weight of the material to be dosed.

• Double use of one scale. Possibility of dosing arids and cements in the same scale.

• Dynamic adjustment of the vein. Each time a weighing cycle of a material ends, the value of the vein is adjusted according to the amount of material below or over the dosed amount.

• Correction of the amount of water according to the humidity of the arids. Starting from a particular percent of superficial humidity introduced through the keyboard or by the sensor for each arid, the correction of water and arids is performed up to a second degree to obtain an adequate balance in the final mixture.

• Materials double flow dosing. In order to obtain the most precision in the dosage of cements, the process can be controlled in two stages: a quick initial one, where most of the amount is dosed; and a final slow one, where the last kilograms are dosed.

• Additives dosing. Additives can be dosed in a volumetric or gravimetric way.

• Constant checkup of the scales. When an scale parameter like capacity or tare is exceeded, an error message is sent to the operator.

• Error correction in Materials dosing. The amounts below or over their corresponding values that were dosed in a cycle are corrected in the following cycle.

• Printed outputs of the results at the end of the dosing process. Actual and expected values are printed as well as any other report requested by the client.

• Inventory in kilograms of each material.

• Possibility of printing the recipes, and the configuration parameters.

• Tolerance control. The production process is stopped whenever a material scheduled tolerance is exceeded.

• Possibility that the operator pauses the process. The process can be paused at any moment that the operator determines, in case of difficulties during the process of production. After solving them, the operator can resume the process.

• Unload of the scales by stages. It is possible to define up to three unload stages.

• There are three types of procedures for the transportation of the arids:
  ✓ Direct. The arids are directly discharged by gravity into the concrete mixer or the concrete mixer truck.

  ✓ Conveyor belt. The arids are discharged on a conveyor belt for carrying them to their final destination. In this case the program considers the time the conveyor belt takes in transporting the materials; this parameter is also configurable.

  ✓ Skip. The arids are transported in a receptacle well-known as Skip. In this case the program keeps track of the ascending and descending movements of the Skip.
• Automatic control of the blending and emptying procedure in stationary mixer. The blending and discharging time can be programmed in such a way that the operator doesn't have to participate in this part of the process.

• Opening and closing control of the gates. The condition of open or closed of each gate is supervised by checking the signals coming from run-end indicators that could be installed in the gates. If the corresponding signs are not generated after having elapsed the scheduled time for opening or closing of the gates, a signal is emitted indicating such condition.

• Intermittent discharge (emptying) of scales. The opening and closing times for the discharge of the gates are programmed by the user. This prevents truck overflows of materials.

• Alternatives for loading the mixer. There are two possibilities to be selected by the user:
  ✓ Independent discharge cycle. When the weight is reached, the container is discharged into the mixer and the next weighing cycle begins, without the need to wait for the weighing and discharging of the other scales.

  ✓ Discharge cycle commanded by the operator. Once the weight is reached, the operator is informed that the materials are already weighed and his confirmation is awaited for discharging them into the mixer.

• Three configurable methods to carry out the automatic control of the dosing:
  ✓ Using an On-Off Control. It allows to define the period of control.
  ✓ By means of a PID Control. The parameters previously defined by the controller can be adjusted during the process.
  ✓ Using an On-Off Control with intermittent leaking. This procedure begins with an On-Off Control and ends with an intermittent leaking system.

• Configurable discharge control. For the discharge it's necessary to consider the following parameters: maximum tare, time of maximum tare, and time of discharge; all of them can be configured by the operator.

• Help: The operator has a very easy Help with the explanation of all configurable parameters and specific instructions about the operation of the system.

Operation:

The system presents a very intuitive graphic interface, of easy handling and understanding, and because of it there is no need to have previous computer knowledge to operate the system. Thus, after the plant is configured and defined the humidity of the arids (which can be introduced by keyboard), the operation is very simple: the operator selects the desired recipe, defines the concrete volume to manufacture and pushes a button; then he only has to wait for the plant to finish the production of the amount of concrete that was ordered. After finishing the whole process, he can know the particulars details by selecting the appropriate production reports.

2.4 REPORTING AND INVOICING MODULE

This module is a software that collect the information from the different plants and allows to issue the billing of the production to the clients and to print the different reports previously detailed in the section devoted to explain the control program. Therefore, this module centralizes the information of the general activities in all plants.

3. CONCLUSIONS

At present in Cuba there are 71 premixed and prefabricated concrete plants in operation; 24 are automated and 19 of them are using this system which, besides the objectives outlined in the introduction of this document, the following advantages have been attained:

• A more rational use of labor in the plant, as the automated system assumed functions that previously required more personnel.

• An increase in the speed of production of the plant, in some cases up to 50%, because the system can simultaneously weigh materials in all the installed scales, thus reducing the processing time in each cycle of the plant.

• Possibility of having a better control on the consumption of raw materials, taking advantage of the reports offered by the system.

• Reduction of the invoicing time.

• Reduction of costs.

• Higher general efficiency in the operation of the company.
Towards an Intelligent Job Site:
Status of the NIST Automated Steel Construction Test Bed

by

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ABSTRACT: The NIST Construction Metrology and Automation Group, in cooperation with the NIST Intelligent Systems Division, is researching robotic structural steel placement through an ongoing program entitled “Performance of Innovative Technologies for Automated Steel Construction.” This program, initiated in response to an American Institute of Steel Construction request for a 25% reduction in time to erect steel structures, focuses on the development of an Automated Steel Construction Test Bed to research advanced concepts in crane automation, laser-based site metrology, laser radar (LADAR) imaging, construction component tracking, and web-enabled 3D-visualization. This test facility also provides a mechanism to investigate paths towards an Intelligent Job Site as described in the FIATECH Capital Projects Technology Roadmap.

KEYWORDS: construction automation, path planning, robotics, steel, VRML, 3-D coordinate measurement systems.

1. INTRODUCTION

FIATECH is a non-profit consortium of facility owners, operators, contractors, suppliers, government agencies, and government and academic research organizations dedicated to the development and deployment of technologies to improve the delivery process of capital projects. These targeted technological improvements span all phases of capital project delivery including design, engineering, construction, and maintenance [1]. The recently published FIATECH Capital Projects Technology Roadmap (CPTR) describes a vision of the future construction project. One element of the CPTR is the Intelligent Job Site (IJS), which is defined as follows:

“Future job sites will be fully sensed and 'wired' to provide continuous awareness of the status of all resources and activities against the detailed construction execution plan defined in the master facility model. Personnel and intelligent equipment will have instant access to all information needed to accomplish their tasks, troubleshoot problems, and re-plan on the fly to accommodate changes. Resources will be finely

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³ Certain commercial equipment, instruments, or materials are identified in this report in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.
coordinated to deliver labor, materials, equipment, and tools to the site when needed, greatly reducing inventory and staging requirements. Site monitoring and control systems will continuously track progress and quality of work against the build plan, and assure the safety and security of the site and all of its workers and resources [2].”

NIST Construction Integration and Automation Technology (CONSIAT) researchers are working with FIATECH to define the various elements, functions, needed research, and development projects for the Intelligent Job Site.

In a related CONSIAT effort, the NIST Construction Metrology and Automation Group (CMAG), in cooperation with the NIST Intelligent Systems Division, is researching robotic structural steel placement through an ongoing program entitled “Performance of Innovative Technologies for Automated Steel Construction.” This program, initiated in response to an American Institute of Steel Construction request for a 25% reduction in time to erect steel structures, focuses on the development of an Automated Steel Construction Testbed (ASCT) to research advanced concepts in crane automation, laser-based site metrology, laser radar (LADAR) imaging, construction component tracking, and web-enabled 3D-visualization. This facility will be used for the testing and validation of advanced tools, methodologies, and standards for automated steel construction, and will provide a mechanism to investigate paths towards an Intelligent Job Site as described in the FIATECH Capital Projects Technology Roadmap.

This paper will discuss recent accomplishments, near-term development, and long-term research efforts associated with the ASCT.

2. SYSTEM OVERVIEW

The Automated Steel Construction Testbed has five primary functional elements. These include: (1) The NIST RoboCrane, (2) a Site Measurement System (SMS), (3) a High-level Controller, (4) a Component Tracking System, and (5) a three-dimensional (3D) Visualization system. The RoboCrane, the SMS, and the High-level Controller are discussed in sections 2.1 through 2.3. The reader is referred to [3] for a discussion of the

Component Tracking System and the 3D Visualization System.

2.1 NIST RoboCrane

A specialized six degree-of-freedom (DOF) crane invented by the NIST Intelligent Systems Division (ISD) is used as the base platform in the ASCT. The RoboCrane is an inverted Stewart platform [4] parallel-link manipulator with cables and winches serving as the links and actuators, respectively. The moveable platform, or “lower triangle,” is kinematically constrained by maintaining tension in six cables that terminate in pairs at the vertices of an “upper triangle” formed by the cable support points [5]. The RoboCrane concept has been modified and adapted for numerous specialized applications [6, 7, 8]. The configuration used in this project is the Tetrahedral Robotic Apparatus (TETRA). In the TETRA configuration, all winches, amplifiers, and motor controllers are located on the lower triangle in Figure 1. This arrangement provides greater flexibility in adapting the platform to existing overhead lift mechanisms. Figure 1 depicts the RoboCrane upper and lower triangle arrangements. The prism planes formed by the dotted lines show the crane’s generalized work volume.

![Figure 1. RoboCrane Cable Arrangement](image-url)
2.2 Site Measurement System (SMS)

A commercially available Site Measurement System (SMS) is used to track the position and orientation (pose) of both RoboCrane and objects within the work volume. The system employs stationary, active-beacon laser transmitters and mobile receivers to provide millimeter-level position data at a nominal 10 Hz update rate. Line-of-sight (LOS) must be maintained to at least two transmitters to calculate position.

Four laser transmitters are placed around the perimeter of the ASCT to ensure the receivers maintain LOS to at least two and preferably three transmitters.

Three SMS single-detector optical receivers are mounted on RoboCrane at the vertices of the lower triangle. This arrangement is illustrated in Figure 2, which also shows an enlarged view of one of the receivers. Position measurements from each receiver are wirelessly transmitted to a position server, which provides RoboCrane pose information to the high-level controller. Figure 3 depicts RoboCrane docking using SMS-derived pose information.

Mapping between the SMS coordinate frame and the site coordinate frame is accomplished by measuring control points with the digitizing tool. Since the vertices, or “anchors”, of the RoboCrane upper triangle are known within the site coordinate frame this yields:

\[
\text{Anchor}_{\text{SMS}} \times \text{Site}_{\text{SMS}} = \text{Anchor}_{\text{Site}}
\]

\[
\text{Detector}_{\text{RoboCrane}} \times \text{RoboCrane}_{\text{SMS}} = \text{Detector}_{\text{RoboCrane}}
\]

is known based on the initial calibration of the three receiver locations on RoboCrane. This yields the pose of RoboCrane within the Anchor frame by:

\[
\text{Anchor}_{\text{RoboCrane}} \times \text{RoboCrane}_{\text{SMS}} = \text{Anchor}_{\text{RoboCrane}}
\]
This calculation enables a direct comparison and correction of the RoboCrane work platform pose calculated from cable-length encoders to the pose measured by the SMS.

Figure 4. Operator with the SMS Digitizing Tool

2.3 High-level Controller

The NIST RoboCrane was initially designed to function in a teleoperated mode, with user commands from a 3D joystick providing input for proportional velocity control. In strictly teleoperated mode, the pose of RoboCrane is calculated based on cable lengths set and then updated through winch encoders. Knowledge of RoboCrane’s pose within the work volume is necessary for safety concerns such as keeping the robot within its designed work envelope. The initial cable lengths are hard-coded into the software and an encoder value to cable length mapping takes place during an initial homing procedure.

In order to provide autonomous control of RoboCrane without significant modification of the original controller, a high-level controller was developed to replace the human joystick operator. This additional controller provides numerous functions including goal state management, world model maintenance, and path planning. A functional block diagram showing the relationship between the two controllers is shown in Figure 5.

The high-level controller receives encoder data from the RoboCrane controller and compares them with data from the SMS. The high-level controller then sends back velocity commands that move RoboCrane. The RoboCrane controller, a version of the NIST Real-time Control System (RCS) implemented in the early 1990’s, converts these velocity commands to winch controller inputs that effect the desired movement. Closed-loop position feedback from the SMS-calculated pose enables periodic modification of the path until the desired RoboCrane pose is reached. Currently this adjustment is made by simply subtracting the calculated drift from the encoder-based pose. Though this technique is effective, it does not provide a real-time method of pose estimation during movement. A more robust pose estimator which filters both sources of pose information is under development.

3. RECENT RESULTS

Currently, we are able to achieve autonomous placement of a steel beam into a randomly placed target structure using RoboCrane, the SMS described above, and a rudimentary path planner. In recent experiments at NIST, RoboCrane was able to autonomously place a beam in a specially designed holder, albeit at a relatively slow speed not yet suitable for construction purposes. A brief description of the placement process follows.

Once the SMS has been set up and calibrated, the target beam holder is randomly placed within the RoboCrane work-volume. Using the SMS digitizing tool, the holder’s pose is measured and entered into the high-level controller. The high-level controller requests RoboCrane’s pose from the position server and calculates the required velocity commands that will move the robot to place the beam in the holder (the beam is currently fixed in the robot’s grippers). At each waypoint, the robot stops and a new estimate of its pose is requested from the position server by the high-level controller. This process is automatically repeated until the beam is docked.

4. FUTURE WORK

Although this work will demonstrate the ability to perform autonomous steel beam pick and place, it will do so in a fairly structured environment that remains static after initial measurement. The measurement process itself, although simple, still requires a human operator within the site to provide the initial digital model. There are currently no sensors, external or on-board RoboCrane, which
would enable any reaction to dynamic changes within the work site without human intervention.

CMAG is currently researching automatic scene meshing and object recognition using high-resolution LADAR (laser detection and ranging) systems. In future work, LADAR and/or standard optical imaging systems will be used to develop and maintain the world model as well as provide obstacle avoidance and docking support. The use of the SMS technology to provide autonomous control of cable suspended robots will also be studied for other applications such as aircraft maintenance and shipbuilding. As additional sensing systems are employed, the SMS technology will also be used to study the performance metrics of other tracking technologies. The ASCT treats sensor input in a modular fashion; thus, future versions could use other positioning technologies such as phase differential GPS in certain applications to replace the present laser-based SMS.

5. CONCLUSIONS

In response to industry demand for improved steel erection, NIST is developing an Automated Steel Construction Testbed to research advanced concepts in crane automation, laser-based site metrology, laser radar (LADAR) imaging, construction component tracking, and web-enabled 3D-visualization. The current system uses RoboCrane, a robotic crane that has been in development at NIST since the late 1980’s, as its base platform. The autonomous system also incorporates a commercially available, laser-base site measurement system and a preliminary version of a newly developed, high-level controller that is software-based. Using these technologies we have been able to autonomously place a steel beam inside a specially designed holder. Development of the NIST Automated Steel Construction Testbed is ongoing and future work will incorporate new sensing technologies as well as more sophisticated path planning and sensor fusion techniques. We are also working on significantly increasing the system’s pick-and-place rate in an effort to meet or surpass current steel construction practices.

6. REFERENCES

Figure 5. High-Level Controller Functional Block Diagram
Experiences with the Design and Production of an Industrial, Flexible and Demountable (IFD) Building System

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ABSTRACT: The Dutch government encourages innovative construction by subsidizing cohesive industrial, flexible and demountable building (IFD) pilot projects. Industrial building concerns the process-related aspects of production, robotization, mechanization, automation, prefabrication, communication, etc. Flexible building involves products that are made in accordance with customer’s wishes and the possibility to make adjustments when the building is in use. Finally, demountable refers to the sustainability of the building.

This paper describes the experiences relating to the design and production of a demonstration project (IFD Today) for an apartment building system on the Eindhoven University of Technology campus. A housing corporation had commissioned the design of an industrial, flexible and demountable building system for flats, on an existing foundation, the surface area and floor plan of which had to be adaptable during use. The current flats do not meet present requirements as set by the government and the occupants, and renovation is too expensive. The data was obtained through participation in the design team and close production monitoring. The paper focuses on industrial building.

After monitoring the design and production process, the following conclusions can be drawn:

• IFD building requires co-operation and a multidisciplinary approach during the design process. Essential issues to be considered during the design process are the tasks, choice of designer, design tools and the expected result. Design meetings must also be organized.

• Due to the lack of a suitable model to calculate the production, operating, renovation and demounting costs and the absence of a marketing plan, conventional designing solutions were frequently applied.

• The steel structure and floor panels were mounted very quickly. This was in contrast to the outer walls, roof, fittings and finishing elements.

• It is advisable to entrust one specific company with the responsibility for a number of production tasks, such as planning, making and checking the drawings, and allocating labor resources with regard to transport and safety.

KEYWORDS: Building Site, Building System, Industrial Construction, Multidisciplinary Design.

1. INTRODUCTION

A trial module was built on the Eindhoven University of Technology campus to gain experience with the design and production of an IFD building system. This paper presents the findings. The first paragraphs explain the concept of IFD building, the IFD Today project and how the study was set up. Finally, conclusions and recommendations are made with regard to the marketing of the IFD building system, based on the results of the study.

2. IFD BUILDING

In the Netherlands, a program entitled ‘Industrial, Flexible and Demountable Construction Demonstration Projects’ has been developed by the Ministry of Economic Affairs and the Ministry of Housing, Spatial Planning and the Environment. This program was developed to promote the innovative application of industrially developed and manufactured construction components in the construction and renovation of homes and public utility buildings.

IFD building provides an integrated approach to the initiation phase, the design, production and use of buildings, and is characterized by early co-
operation between the parties, enabling alignment of the concept, design and execution. The industrial production of components offers increasing opportunities for flexible use. Demountable building enables a separate replacement of components with various lifespans, thereby extending the life of the building as a whole. As such, IFD building is a form of sustainable building. [SEV]

Van den Brand describes IFD building as a three-pronged strategy to innovate the building process: the client (flexible), the manufacturer (industrial) and society (demountable). This is characterized by the following principles: ‘level-thinking’ [building - floor - room - work station], a fixed form and space combined with variable options for the interior, a multidisciplinary design, separate technical systems; dimensioning and nodes; modularity and demountability. [Van den Brand]

3. IFD Today

Between 1945 and 1963, about 400,000 apartment buildings were constructed in the Netherlands with the following characteristics: traditional design, the use of clay, no insulation, poor sound insulation. They were, almost without exception, four-storied staircase-access flats. Between 1964 and 1975, another 475,000 medium-rise apartment buildings and 300,000 high-rise apartment buildings were constructed. Today, these apartments still have poor (sound) insulation (see figure 1).

![Figure 1. Apartment blocks.](image)

The improvement of post-war houses as from 1974 mainly involved the application of insulation. Although heat insulation was improved, the number of problems associated with building physics increased. In spite of substantial investments, very little could be done to improve the living quality. Houses were cramped and inadequately equipped, they had poor sound insulation, and were only accessible by a narrow staircase.

A more drastic approach proved technically impossible or would have required substantial and unprofitable investments. The current demand for houses is very diverse in terms of surface, layout and fittings. Even in cases where a drastic approach was adopted, the required level of housing differentiation could not be achieved within the existing shells. For this reason, more and more post-war houses will be demolished. [IFD Today]

A partnership (IFD Today) between the Amnis housing corporation, contractor Heijmans IBC, installer Stork and the Eindhoven University of Technology has chosen to solve the above problem with IFD building. A design team comprising staff employed by the partners was instructed to develop an IFD building system using existing technology.

4. IFD BUILDING SYSTEM

According to Eekhout, a building system is an orderly collection of construction elements and construction components with connecting facilities, which can be combined or applied in various ways, in accordance with regulations or agreements and depending on the environment. [Eekhout]

The building system process is characterized by the following aspects: technology, the human factor, information and organization. The building system product is characterized by the aspects of function, flexibility, geometry, materials, structural and technical capacity, complexity and cost. The dominance of the aspects depends on the market in question. The production of frequently used construction elements has now largely been mechanized or is carried out by robots, for example. Specific construction elements requested by the client are manufactured in the traditional way.

The conceptual design in IFD building is based on six specific values of a building:

- Basic value: achieving a building physics level that is higher than current standards.
- Use value: aiming for as much layout freedom as possible at building, story and apartment level and with regard to individually adjustable and quantifiable installations.
• Local value: achieving a building system that allows differentiation possibilities according to type, surface, layout, fittings and architecture.
• Ecological value: reusing foundations and the necessity of applying light structures.
• Economic value: developing a product in line with marketing conditions.
• Strategic values: constructing a building that can be adjusted in the course of time.

These values can be considered on four different levels: the built environment, building, house and living quarters level. The conceptual design addresses the design aspects, viz. the requirements, design, quantification and design strategy.

Hendriks has developed a number of design criteria for IFD building:
• Integration and independence of disciplines: installation, bearing structure, outer shell and interior finishing.
• A completely dry building method: no pouring of concrete, mortar joints, screeds, stuccowork, sealant or PUR spray.
• Perfect modular dimensioning: a great deal of attention to drawings, prototype testing, quality system for drawings, and assembly instructions.
• Adjustability of all parts: bearing structure (limited), installation (practically unlimited), outer shell (limited and modular), interior finishing (practically unlimited and modular). [Hendriks 1999]

The IFD building system has the following characteristics:
• A steel support construction of hot-rolled standard profiles, L-supports at the corners, and I-supports and joists on the grid line.
• The supports provide stability and the joists have been fixed to the bearers in such a way that vibration is kept to a minimum. The floor panels are placed on the joists.
• The floor panels are hollow to enable the inclusion of technical installations. See figure 2.
• Piping can be placed in the supports and the floor panels at the plant or the building site.
• Non-bearing walls dividing houses and rooms can be placed anywhere.
• Free choice of outer wall.

• There is no specific roof design. The traditional solution is adopted, i.e. warm roof.

Characteristic elements of IFD building are:
• An 11-meter span and a 7.2-meter grid.
• Optimal free space providing various layout possibilities.
• Maximum flexibility with respect to vertical and horizontal piping, providing various possible locations for toilets, kitchens and bathrooms. [Systeemcatalogus IFD Today]

5. STUDY

To gain experience with the IFD building system, a trial module was built on the DUBO (Sustainable Building) park on the Eindhoven University of Technology campus. The trial module is fourteen meters wide and eleven meters deep, and has two stories. See figure 3.

Not only the trial module’s design process but also its production process was assessed for its IFD characteristics. This report only describes one aspect of IFD building, viz. industrial building.
According to its conceivers, the IFD technology makes use of the following traditional elements of industrial building:

- Production at the plant.
- Mechanized production.
- Mass production.
- Co-operation is independent of projects.
- Deployment of information technology.

Today, the emphasis in industrial building is on:

- Customer-oriented production and marketing.
- Flexible production systems.
- Subsystems are independent but can be combined.

[Hermans]
The transfer of production from the building site to the plant has resulted in an integration of functions and sometimes materials of a component or a system of components. This requires a high level of component alignment (specifications, dimensioning, finishing) [Bouwen op kennis]

For the purposes of this study, the following description of industrial building is used: the transfer of physical tasks from the building site to the plant and from people to machines and computers. These tasks do not involve building alone but include the collection and processing of data, consultations and alignment, optimization and planning.

It is apparent from this description of industrial building that designers from various disciplines – architectural designers, building physics designers, electrical and mechanical designers, construction designers and implementation designers – are involved in joint designing from an early stage.

5.1 Design process study

The trial module was designed in close co-operation by a team consisting of an employer, architect, structural engineer, fitter, contractor and representatives of the supply industry. An attempt has been made to describe the experiences gained through intensive participation in design meetings:

- The preparation for the meetings was limited to an agenda.
- Other subjects, such as planning, subsidy applications, composition of the design team, were also discussed.
- The fitter, in the capacity of installation consultant, aims to find quick solutions.
- The fitter discusses solutions a great deal.

- Little use was made of sketches in the concept design phase.
- Design problems were passed on to the subcontractors, who then solved them independently.
- Production costs were calculated in the traditional manner.
- Design problems were still being solved in the execution phase, usually at the building site.

During the building phase of the trial module, the meetings between the designers and the parties executing the work were sometimes reminiscent of a site meeting.

During the design and production process, a list of points for improvement was made, which could be used during a subsequent design process.

5.2 Production process study

The production process is considered a transformation of materials into a building, with waste as a by-product. The transformation is carried out by people and tools and managed using plans, drawings and instructions (monitoring). See figure 4.

![Figure 4. Model of the production process of a building.](image-url)

The following aspects of the production process can be observed:

- The production process: preparation, transport, storage, treatment, processing, conditioning.
- Materials, construction elements, construction components.
- The building and (separate) waste flows.
- The people: planners, project manager, supervisors, construction workers, mechanics.
- Labor resources: tools, scaffolding and accessibility structures, transport equipment.
• Management: planning, schedules, instructions, drawings.

The findings obtained during close monitoring of the production process at the plant and at the building site were recorded in a log, filmed or photographed. Explanations, comments and points for improvement are provided for photographs depicting extraordinary situations. Table 1 gives a concise overview of the findings and points for improvement for each aspect. [Van Gassel]

6. CONCLUSIONS

The following conclusions can be drawn after monitoring the design process and production process:
• In IFD building, the design process requires co-operation and a multidisciplinary approach. Matters such as design tasks, choice of designers, design tools and expected results must be considered during the course of the design process, and design meetings must be organized.
• Due to the lack of a suitable model to calculate the production, operating, renovation and demounting costs and the absence of a marketing plan, conventional design solutions are frequently chosen.
• The steel structure and floor panels are demounted very quickly. This is in contrast to the outer walls, roof, fittings and finishing elements.
• It is advisable to entrust one specific company with the responsibility for a number of production tasks, such as planning, making and checking the drawings, and allocating labor resources for transport and safety.

7. RECOMMANDATIONS

The IFD building system should be treated as a comprehensive product and be marketed by one company or a cluster of companies. The company or cluster of companies should develop an IFD cost model and marketing plan for this purpose. The marketing plan should address at least the following elements: living concepts, mass customization, adaptability at all phases of the building’s economic life, period of use versus economic life, customer order release point, long-range production planning etc. Specific skills required for the organization and facilitation of and participation in design meetings could be obtained by a mutual exchange of knowledge.

8. REFERENCES


[SEV] SEV, Leaflet IFD and www.sev.nl

[Systeemcatalogus IFD Today] Internal IFD Today publication.
### Table 1. Findings and points for improvement with regard to the production process.

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Findings</th>
<th>Points for improvement</th>
</tr>
</thead>
</table>
| Materials    | • Additional production space was needed at the plant to mount technical installations into the steel construction.  
• Mechanics had to determine reference points and dimensions themselves as these were not indicated on the drawings submitted.  
• The production of large elements was treated as a project instead of serial production.  
• Mechanics frequently tried to mount installations at the building site instead of at the plant.  
• Parts were selected and the assembly order was determined at the building site.  
• Small materials were delivered unsorted and in bulk. As a result, much sorting was needed and materials got damaged.  
• Special assembly drawings should be made.  
• Investments should be made in mechanization and robotization.  
• Construction components should be coded.  
• Materials should be supplied in crates and using additional means of transport.                                                                                                                                                              |
| Management   | • Each supplier submits its own drawings. Connections between construction components of the various suppliers were not provided and a solution had to be found on site. Many telephone calls were needed to obtain the required assembly information.  
• Drawings should be made of the connections between the construction components.  
• Specifications should be of a quality that the need for drawings and instructions is eliminated.  
• A project database and project extranet should be used.                                                                                                                                                                           |
| People       | • Different types of scaffolding were erected for different parts of the work.  
• Traditional safety provisions such as edge protection were used.  
• One type of scaffolding should be used.  
• Safety provisions should be integrated in the building system.                                                                                                                                                                         |
| Labor resources | • Various types of cranes were used, sometimes as many as four at the same time.  
• Special labor resources were made and deployed at the building site for the purpose of the project.  
• One type of crane should be used during the execution process.  
• Specific labor resources should be designed.                                                                                                                                                                                             |
| Waste        | • Much waste was produced during the fitting-out process.  
• Waste was not collected separately.  
• Returnable packaging should be used.  
• Work on material carried out at the building site should be kept to a minimum. This should be confined to the plant as much as possible.  
• Waste should be separated in accordance with government regulations.                                                                                                                                                                    |
| Building     | • Building physics measurements showed that a number of details had not been finished properly: noise leaks, air leaks, etc.  
• Details should be finished properly.                                                                                                                                                                                                                       |
Business development opportunities for robotics in Dutch construction industry

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ABSTRACT: This paper describes a research project of the Dutch foundation for building research, aimed at identifying and describing the key technologies for robotics and automated production systems in the building & construction industry. The project focuses on the Dutch building & construction industry (housing & utility buildings excluding civil engineering constructions). The main goals of the project are to:

- Describe the available technologies, relevant for automated production systems, currently referred to as:
  - Construction robots and/or computer-controlled machines
  - Automated building factories
  - Computer-aided manufacturing
- Identify the opportunity area’s for successful implementation of automated production systems
- Describe the consequences of applying automated production systems for the organization of small and medium-sized enterprises (SME’s)
- Develop a detailed plan for knowledge transfer.

KEYWORDS: Off-site construction, product/market/technology mapping, business development, SME’s.

1. INTRODUCTION

Traditionally in the construction industry the production activities are concentrated on the building site. The last decades however, a shift towards prefabrication and off-site production can be recognized. By relocation of production activities towards a factory environment the building production process can become more efficient and better controlled. When in such a factory environment buildings and/or building components are produced according to industrialized manufacturing principles and concepts, we speak in this paper of an industrialized construction process.

Automated production systems can play a major role in industrialized construction processes because the advantages of prefabrication can be further enhanced:

- Technical quality of the end product can be controlled better, leading to constant quality which better meets the expectations of clients
- Working conditions for construction workers are better (weather independent and replacement of routine activities by computers/machines)
- Productivity in the construction industry can be improved
- Because of the replacement of human labour by machines/computers, human resources are better manageable in times of economic fluctuations and changing workvolumes.

2. TAKING NEW TECHNOLOGIES TO THE MARKET

Despite the potential advantages of automated production systems, these systems and their associated technologies have not penetrated the building & construction industry on a large scale, because of several reasons.

2.1 Market considerations

The market for construction projects is heterogeneous. Differences in clients needs, building function and characteristics and physical site-circumstances for example lead to different building & construction approaches. Some approaches allow application of industrialized manufacturing concepts more than others. Although industrialization of the building & construction industry cannot be stopped, the
expectation is that their will always to some degree be projects which require building & construction approaches based on traditional technologies.

Automated production systems should therefore be targeted to those market segments in which they add the most value. Systems which are successfully implemented in one country will not automatically be suitable in another country because of differences in market volumes, industry structure etc.

2.2 Business strategy & operations

Implementation of automated production systems requires investments of individual companies in technology (hardware, software) and people (training & development). In many cases the introduction of automated production systems will have consequences for the internal organisation. The relations between the calculation department, the engineering department and the workfloor will change. Business operations will have to be redesigned.

Except for the internal organisation, implementation of automated production systems can also have an impact on the external relations. Many contractors and subcontractors/suppliers of building components work in business-to-business markets and interact with other stakeholders in the building & construction supply chain. So these investments in automated production systems should be part of a company strategy and a sound integrated view on business definition (in which business are we in?), products & services, markets.

2.3 Knowledge infrastructure

The acquisition, installation and operation of automated production systems requires specific know how and expertise. To make a sound investment decision, knowledge about the possibilities and limitations of the systems and associated technologies is needed. Also the implementation and use of these systems may require knowledge and skills which are not available in the company and will have to be acquired.

Taking everything into account, we can conclude that for many construction companies and subcontractors, which are small & medium sized enterprises (SME’s) the decision to adopt and implement automated production systems is difficult because of a lack of knowledge and insight in the business development opportunities.

3. RESEARCH QUESTIONS & APPROACH

The project addresses the following questions:

• Which technologies, associated with automated production systems are relevant and available for the building & construction industry.
• To what degree and in which form are these technologies currently being applied by the industry.
• Which product/market/technology combinations offer opportunities for applying automated production systems.
• What kind of knowledge-transfer will be necessary to accelerate the adoption of the technologies in the opportunity-rich market segments.

The overall structure of the research project is shown in Figure 1. The project is currently in the start-up phase. The project is planned to take off in the final quarter of 2003.

4. TARGET GROUP FOR THIS STUDY

In the construction industry, the supply chain can be complex and fragmented. From the suppliers of raw materials unto the handover of the building to the end user, a lot of stakeholders and businesses are involved. Because the supply chain in the total construction industry is too comprehensive to study as a whole, a decision has to be made on which part of the supply chain to include in this project.

As is shown in Figure 1, which shows a hierarchy of building products (based on Eekhout), this project is limited to automated production systems for buildings, building parts, building components and sub-components. This for example means that automated production systems for producing cement and bricks will not be covered in this project but that automated production systems for producing prefabricated façades will be.
Table 1. Hierarchy of building products

<table>
<thead>
<tr>
<th>Name</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw material</td>
<td>sand, gravel</td>
</tr>
<tr>
<td>material</td>
<td>Cement</td>
</tr>
<tr>
<td>compositematerial</td>
<td>concrete, glassfiber reinforced polyester</td>
</tr>
<tr>
<td>semifinished product</td>
<td>aluminium profiles, metal plates</td>
</tr>
<tr>
<td>element</td>
<td>Bricks</td>
</tr>
<tr>
<td>subcomponent</td>
<td>window, frame</td>
</tr>
<tr>
<td>component</td>
<td>cladding panels, roof panels, prefab concrete floorsheets</td>
</tr>
<tr>
<td>buildingpart</td>
<td>foundation, façade, roof</td>
</tr>
<tr>
<td>building</td>
<td>school, office, house</td>
</tr>
</tbody>
</table>

Based on: [Eekhout]

So the research activities will concentrate on the use of automated production systems by the following target groups:

- Building contractors with inhouse workshop facilities and factories for prefabrication
- Subcontractors/producers of prefabricated buildings (timberframed, steelframed, systems builders)
- Producers of subcomponents and components (prefab concrete sheets, façade systems, frames etc.).

The role of the other stakeholders, for example the architect and the client will however not be neglected.

5. FINAL CONSIDERATIONS & REMARKS

The potential value of this project related to an earlier study of SBR [SBR] and to for example the IFD-programme [SEV] is that in this project technology is linked to marketing. The purpose of this project is to identify market segments in which structural application of automated production systems is feasible. In this way the project aims at stimulating project independent innovation.

It is expected that after finishing this project the target companies are informed about automated production systems and the associated technologies in a way that they should be able to:

- Recognize the possibilities for automated production systems in their own corporate context.
- Make a balanced decision about the possible introduction of these systems in the own organisation.

- Find support for setting up implementation and introduction projects in their company (financial support through subsidies, consultancy, training etc.).

6. REFERENCES

[Eekhout] Eekhout, Mick, 2003, 
Faalkostenreductie en industrialisatieconcepten, 
Paper BouwBeter Congres, Stichting Bouwresearch.


Figure 1. Overall structure of the research project
ABSTRACT: Information about products for the construction industry is increasingly often provided to designers in digital ways that enable them to apply the information directly in the design process. Digital product catalogues are provided using various media and formats and several initiatives are taken by the industry and by CAD developers to integrate this kind of information into CAD systems. Generally, current practice is to distribute the information to designers, for example, by using CD-ROMs or a website where the information can be downloaded. In our research we recognise that distributing information in this manner detaches it from the business processes in the construction supply chain, which is a major disadvantage.

The project presented in this paper concerns the implementation in the Dutch construction industry of a methodology for sharing product information through a distributed object model. The methodology, which is called Concept Modelling, forms a generic basis for the support of collaborative design, but is applied in this project to the integration of information from the supply chain in the design process. Through the distributed object model, design information and product information can be integrated while the actual data objects remain at their source. This enables the supply chain to provide information of a high semantic level to designers while keeping the control over the information and maintaining the relationship of the information with their business processes.

The advantages of this approach in which information is shared, rather than exchanged, are numerous. Redundancy of information is minimised, consistency is improved, and updated information is available immediately. Moreover, design and construction processes can benefit significantly from the dynamic aspects of accessing information that is tied to business processes in the supply chain. For example, product selection during design can be based on latest information on product details, prices, production methods, and variants of products. This information can be provided to designers automatically and on demand.

KEYWORDS: Collaborative Design, Product Data Modelling, Concept Modelling, Distributed Object Model, Semantic Web.

1. INTRODUCTION

The availability of adequate product information is one of the aspects in building design that have a large effect on quality and costs of the construction process and of the final building. Design faults are often caused by incorrect or misconceived product information or by improper selection of products because of lacking information. Such mistakes in the design stage can have dramatic consequences for the construction process, when ad hoc solutions or replacements of products in the least case obstruct the process and invariably are cost-intensive, time consuming, and likely to have a negative effect on the eventual quality. If such mistakes become evident only later, while the building is already in use, the possibilities for correction are often very limited and the costs much higher. A survey by (Josephson and Hammarlund 1999) shows that 15-30% of all defect costs during production are caused by design mistakes. After construction, during maintenance, design mistakes are the cause of 40-55% of the defect costs. The same study shows that over 60% of the defect costs in construction that are caused by design mistakes can be traced to a lack of knowledge or information.

The quality and availability of product information depends largely on the form and media used to distribute this information. The following aspects determine the value of product information for design:

- Semantics (is the meaning of the information sufficiently defined and understood?)
- Validity (is the most actual information available?)
- Format (can the information be accessed and applied directly in the design context?)
• Timeliness (is the information found and available when needed?)

Current practice in the supply chain of the construction industry is to distribute product information, for example in the form of catalogues, either in paper format or in a digital format that is likewise rigid, such as CD-ROMs or documents that can be downloaded from a website. In the more advanced cases, information is produced on demand by web servers and can thus be tailored to specific requests. However, once provided, the information is no longer in control of the supplier and the consumer of the information has no guarantee of its validity.

The usability of product information in design processes also depends on how well the meaning of the information is understood by the user. Obviously, design support systems require a high level of explicit semantics to be able to interpret and process data.

The research project described in this paper is named CoDesKs, for Collaborative Design Knowledge services. The objective of this project is to offer a paradigm for information modelling and communication in design that on the one hand enhances the explicit semantics of information and on the other hand improves the validity and timeliness of information in a collaborative design environment.

2. DISTRIBUTING PRODUCT INFORMATION

The purpose of distributing product information is generally twofold: to communicate about merchandise and to provide details about the technical application and organisational issues concerning the product. There are many reasons why the information concerning a product can become outdated. For various reasons, such as commercial ones, there is a strong urge to innovate, with new models emerging, new materials being applied, new features added, new options, applications, technical solutions, etc. Another cause for the limited validity of product information is its relation to a specific application, for example in a particular construction project. This relation may have an organisational nature, such as contractual agreements on prices and delivery, or a technical nature, for example when the applicability of a product depends on technical aspects of the project design.

Distributing product information through catalogues, on paper or in digital format, does not support the demand for up-to-date or project-bound information. Using websites to download product data only improves the timeliness of information; it does not improve its shelf life. More advanced websites are able to produce customised information, taking project or client specific data into account, but again this does not improve the validity of the information over time after it has been provided.

The validity of information that a designer obtains from partners in a project can only be guaranteed by sharing the information resources. This means that, rather than providing a copy of the information, the information is accessed at its source where the provider of the information has full control (and responsibility) over it.

To achieve such sharing of information, we propose a change of the paradigm ‘distributed product information’ from the supplier point of view to the consumer point of view. ‘Distributed’ no longer means ‘sent to many clients’ but rather ‘accessed at many providers.’ Sharing distributed information resources has the potential to improve business processes in many ways:

• Avoiding unsolicited communication, the traffic of information is reduced, even if there is an increased amount of wanted traffic;
• It improves the validity of information, because it remains under control of the provider;
• It increases the quality of information, since it can answer a specific request or even result from a, possibly automated, dialogue;
• It helps to integrate business processes by keeping the relationships between the processes and their output data active.

This paper first introduces the theoretical and technical features of the so-called concept-modelling paradigm that implements a distributed object model for collaborative design. It then discusses the opportunities that this technology creates for a stronger participation of the supply chain in design processes.

3. CONCEPT MODELLING

Concept Modelling is the name of a modelling paradigm that was developed in the CoDesKs project at Eindhoven University of Technology (van Leeuwen 2003). The objectives of this modelling paradigm (van Leeuwen and Fridqvist 2003) are: (a) to give the end-user (designers or other actors in the building process) authority over the schema
of models that are used for the representation of
designs and products; and (b) to provide a consist-
tent information modelling environment that sup-
ports distribution of data sources and multi-user
access.

The first objective, user authority over the
modelling schema, is addressed by the dynamic
nature of the modelling paradigm. In principle,
this is an object-oriented paradigm, but there are
many features to it that increase its flexibility such
that end-users have a high level of control over the
exact definition (and thus semantics) of objects.

The second objective, consistent multi-user
access to distributed data, is achieved mainly by
the implementation of remote data access, using
Internet technology, in combination with an ob-
ject-level version control mechanism.

Both aspects of the modelling paradigm are
discussed in more detail in the next two sub-
sections.

3.1 User-access to modelling schemata

The concept-modelling paradigm uses the term
concept to denote logical notions on which reason-
ing in design is based. This includes notions of
construction elements, like floors and walls, but
also non-tangible notions, like spaces and routing.
Also, aspects such as colour, strength, tempera-
ture, etc., are notions that are represented by con-
cepts. In the definition of a concept, there is no
distinction between the representation of objects
and properties. This distinction only becomes ob-
vvious in the application of the concept in a modell-
ing context. The reason for this is that a concept
will be viewed upon as an object in one context,
but regarded a property in another. For example, a
concept that represents the notion of ‘usage func-
tion’ in the design of a building will be used as
object in early stages of reasoning about a design,
but will be assigned as a property to spaces during
later stages.

Concepts are defined in a formal manner, using
the following five mechanisms:

- Value representation
- Interrelationships
- Prototypical versus individual concepts
- Multiple inheritance

Value representation and interrelationships
In its most basic form, a concept is a simple
named entity, e.g. ‘length,’ that can have a value,
e.g. the numeric value 5.4, and a unit for this
value, e.g. ‘m.’ More complex concepts are de-
defined through relationships to other concepts. For
example, a concept named ‘steel beam’ would
relate to concepts defining its profile, its material
properties, and the concept ‘length.’ The different
relationships that can exist between concepts are
categorised into: decomposition, association, and
specification. The latter type of relationship indi-
cates that a particular aspect or detail of a concept
is specified by another concept, like the length
specifies an aspect of the beam. Decomposition
relationships denote whole-part type of relation-
ships, e.g., a steel beam is decomposed of a body
and a flange. Associations indicate relationships
between concepts that are in principle independent
but in some way associated, for example the asso-
ciation between a wall and a space.

All relationships between concepts are identi-
fied using role names. These describe the particu-
lar role of the related concept in the context of the
concept that defines the relationship.

Prototypical versus individual concepts
We can reason about design and model a design in
two distinct modes. One mode is to think about
design in terms of typologies. We do this when we
talk about the generic properties of, for example, a
type of building element. For this kind of reason-
ing, we can model prototypical concepts (also
called prototype concepts, or simply prototypes).
On the other hand, when we reason about and
model a particular design case, we need to provide
specific information about the case, which is mod-
elled using individual concepts (or individuals).

While these two kinds of concepts share many
features, their meaning is slightly different1. For
example, the value of a prototype concept denotes
the default, or assumed, value of such a concept.
The value of an individual concept, however, de-
notes the particular value of that concept in the
context of the particular design case.

Individual concepts are always modelled on
the basis of prototype concepts; they instantiate
one or more prototypes and can implement all re-
lationships that are defined for those prototypes.
This way, building elements can be modelled that
integrate multiple design concepts, for example,
an element that integrates the functions of both
wall and furniture.

The difference between prototypes and indi-
viduals becomes particularly evident when look-
ing at the relationships. Relationships defined be-
tween prototypical concepts could be regarded as

1 While this approach addresses the class-instance di-
ichotomy as discussed in (Fridqvist 2000), it does not
completely eliminate the dichotomy, the way Fridqvist
proposes.
the variables of concepts, while the relationships of an individual provide the actual data of those variables. There are many features of the modelling paradigm that make it very flexible and allow, for example, ad-hoc relationships between individuals that have no counterpart in the prototypes.

**Multiple inheritance**

The concept-modelling paradigm implements a multiple-inheritance mechanism: a prototype concept can inherit relationships from other prototype concepts. This allows a structured and layered organisation of design concepts, which is an important feature for standardisation and communication protocols. When a prototype inherits from another prototype, all relationships of the ‘super-prototype’ also apply to the ‘sub-prototype.’ Individual concepts that are based on such a sub-prototype can implement all relationships defined for the sub-prototype and its super-prototypes. Sub-prototypes can override relationships of super-prototypes, in order to make them more specific.

Figure 1 shows a network of prototype and individual concepts. It demonstrates multiple inheritance, as well as the prototyping mechanism.

**3.2 Multi-user access to a distributed object model**

The above-described features of the concept-modelling paradigm allow designers to formalise design knowledge and to model design cases. In practice, they would never do this in isolation: design is always a process of collaboration. Even when a particular task is not performed in direct collaboration with other individuals, a designer will always access or re-use information from external resources. There are many ways to bring together information from multiple resources. Currently the most popular approach is to use project-webs. These are websites where all collaborating partners in a project store their information, making it accessible to all. The main advantages are that such a project-web provides a central entry-point to the project information and allows centralisation of the data-management, such as security, backup maintenance, and document version control.

One major disadvantage of using project websites is that all partners need to be disciplined in keeping the information updated at the server and must refrain from sending information to each other through other routes, e.g. using email. Another major problem with project webs is that they are document-based and draw a strict line between project-specific and project-independent information. Because documents are moved away from their source to the central storage location, information that is in principle independent of projects, such as information describing the products and services of a company, automatically becomes project-specific once it is entered into the project website. As a consequence, this information is disconnected from its source and from the underlying business processes. This implies a considerable risk of inconsistencies and the usage of outdated information.

**Remote data access**

The CoDesKs project has incorporated the concept-modelling paradigm into an object model that

![Diagram of a network of concepts](image)

Figure 1. Example of a network of concepts. The prototype concept 'Office Wall' inherits from the 'Interior Wall' and the 'Sound Absorbing Element' concepts. It overrides the inherited 'height' relationship by fixing it to 2600 mm. The 'Media Wall' is an individual concept based on the prototype 'Office Wall' of which it uses the height; the length is added to this individual. The 'Media Wall' also implements the prototype 'Projection Screen' (no further details shown here).
offers remote access. Essentially, this offers the possibility to build applications that can access objects directly at remote resources. Rather than having to exchange information in the form of documents, such applications can share information in the form of objects.

The technology applied in this approach is standardised, HTTP and SOAP, through the implementation provided by Microsoft™ .NET Remoting facilities.

There are a number of conditions that need to be met before remote data access can be practically applied in a collaborative design context. First of all, objects, and in our case these are concepts, must be uniquely identifiable. For this purpose, concepts are organised using the notion of namespaces that are themselves identified through URI’s (Uniform Resource Identifiers). This mechanism provides the capability to uniquely identify each concept and concept-relationship in a consistent and persistent manner.

A second condition for a proper organisation of remote data access is security. Obviously, data must be protected from unauthorised access, while authorised users must have sufficient rights to read or write data. In the concept-modelling paradigm, the system of access rights is more complicated because there are several levels of access that enable users to read, copy, use, inherit, or modify concepts. Access and ownership is controlled on the basis of user groups.

A third feature required from remote data access is a locking mechanism to prevent simultaneous modifications to objects by multiple users. This is implemented by way of a checkout mechanism. When a user accesses data for modification, the data is temporarily inaccessible for modification by other users. At all times, data remains accessible for operations other than modifications, such as reference or inheritance operations. The period of locking depends on the kind of modification that the user’s application is performing; real-time graphical operations will take longer than non-graphical changes to data.

Finally, notification is a fourth requirement of useful remote data access. When multiple users access the same data resources, they probably like to be informed of modifications to that data. A subscription mechanism allows users to be subscribed to notifications that are sent when data is modified. Examples of such modifications are changes to the design or the release of a new type of a product to the market. To a certain extent, these notifications can be handled by the system automatically, for example to update the graphical onscreen presentation. Other notifications may require human reaction, for example to evaluate the consequences of a change in the design or to consider the application of a new product.

Object-level version control

Version control is necessary in a design system, and particularly in a collaborative design system, for a number of reasons (van Leeuwen and Fridqvist 2003). Firstly, version control is a way of recording user actions. Such a record can be used for many purposes, e.g., allowing the user to undo certain actions or enabling the user to inspect and replay the history of the design process.

Expanding on such a timeline of the design process, the second reason to provide version control is that it can be used to administrate design alternatives.

But in the context of collaborative design, version control of objects is above all important to maintain the consistency of an object model that is accessed by multiple users. Changes to objects are administered through the creation of new versions, which ensures that the state of objects recorded in previous versions will remain available. References between objects can make use of the version information of objects, so that the data consistency is not compromised when new versions are created. Semantic consistency is, of course, not ensured by the implementation of object version control.

In literature, version control at the object level is described in (Cellary and Jomier 1990), who use so-called ‘stamps’ to identify object versions in multi-version databases; in (Bernstein 1997), proposing basic operations on versions that are identified through a succeeds relationship; in (Kimber, Newcomb, and Newcomb 1999) who describe referent tracking documents as a means to control version information through hyperlink management.

Administering versions and revisions of objects provides a means to archive the changes to objects. In combination with authenticated access, it is possible to trace the changes of objects to the users who made those changes. Having a record of the history of each object also facilitates the browsing and restoring of previous states of a design model. This also has potential for, e.g., the narrative representation of designs and for computer applications used in design education and research.

In the concept-modelling paradigm, version information for objects is organised into three levels: major versions, minor versions, and revisions.
These three levels relate to the kinds of modifications that can be made to objects. A modification to an object is started by a checkout of the object, which locks the object for modifications by other users. It is concluded either by committing a new revision or by submitting a new version. Revisions are used to accumulate modifications until the user concludes that a new version is ready to be created. New versions are in principle minor versions, unless either the user or the system requires the creation of a new major version. The system will require a new major version when it cannot automatically upgrade references by other objects to the next version. This helps identify potential consistency issues in the model that require attention by the user.

This approach of storing all modifications as revisions or versions of objects helps to increase the consistency and integrity of the objects and the relationships between objects from various resources. At the same time, it requires smart ways of identifying objects when making references to versions and resolving and updating these references. The object versioning mechanism implemented in the concept-modelling paradigm utilizes timeline management for this purpose. The timeline of an object administrates the beginning and ending of each revision and version. Through this mechanism, it is possible to identify the relevant relationships for a given concept and the concepts that form its context. An example of the timeline of concepts and relationships between concepts is shown in figure 2, which also illustrates the three levels of references required for this versioning system. Details of the implementation and implications of the object version control mechanism and the timeline management can be found in (van Leeuwen and Fridqvist 2003).

3.3 Related developments

The information modelling approach proposed in the concept-modelling paradigm bears much resemblance with technologies such as XML (W3C 2003a) and RDF (W3C 2003b) and with the development of the Semantic Web (W3C 2003c). While a thorough comparison is outside the scope of this paper, it is relevant to mention here that the concept-modelling paradigm could be regarded as a more specific form of semantic web. Where the W3C Semantic Web effort aims to standardize a very generic way of expressing semantics for the context of the world-wide web, the concept-modelling paradigm goes somewhat further in its classification of relationships between objects (comparable to the predicates in RDF). In comparison with the semantic web, the structure of prototype and individual concepts is also more restrictive. The reason for these restrictions is that we believe that the ability to make more detailed assumptions on the structure of information offers us better opportunities to develop more intelligent...
support, for example in the form of case-based reasoning tools and agent technology.

4. OPPORTUNITIES FOR THE SUPPLY CHAIN

The capabilities of defining and sharing active information and its semantics were developed in this project to support an expressive, yet formal, way of modelling designs and to support collaboration between designers. At the same time, these capabilities allow other partners in construction projects, including the supply chain, to become more actively involved in the process of collaborative design. As set out in the introduction of this paper, the availability of product information in the design process has a major influence on the quality and costs of the final design. Therefore, ability to increase their role as active participants in design processes is an exciting opportunity for product suppliers. Besides offering competitive products, the challenge is now to offer high quality information about products and information services relating these products to design projects.

The new technology to share information contents, the semantics of information, and the access to our business processes, opens up almost limitless opportunities in e-commerce. First of all, semantically well-defined information improves the process of product selection and offers a chance to better inform designers about the qualities and features of products. But the implications of this new technology go far beyond this point in improving the relationship between supplier and designer:

• Information objects from the supplier become active objects in the context of the design project. They will update themselves, or notify the designer when updated information is available.

• When enhanced with knowledge about the application of a product, information objects can react to the development of the design, for example by adjusting the features of the product in accordance with its context. This behaviour of the information object does not need to be incorporated into the design application, which is the approach followed in the development of today’s CAD systems. In the distributed object model, design objects and product objects from multiple resources form an integration of knowledge from various disciplines.

• Taking this one step further, the supplier’s information objects can be tied to business processes such as sales, production, and delivery. On the one hand, this allows designers and project developers to take this type of information into consideration already during design. On the other hand, it facilitates and promotes the re-usage of information models from design stages into construction or even facility management stages.

5. IMPLEMENTATION AND CURRENT DEVELOPMENTS

The concept-modelling paradigm is developed and implemented in the CoDesKs project in the form of an information-management module that takes care of all storage, access, and modification actions on the concept databases. This core module also manages the remote access, the object-based version control, and the resolution of object references. It provides an application-programming interface that can be used to develop either client applications or, e.g., web-interfaces. The concept database is currently persisted in a relational database, but interfaces on the basis of XML and RDF are planned.

The results and experience from the CoDesKs project are currently being input in the development of an industrial standard for integrated software for the Dutch architectural design market. This standardisation effort, named Het Digitale Huis (The Digital House) is a project initiated by Dutch CAD vendors and aims to market new software products based on this standard on a very short term. The suite of products that these software houses develop on the basis of this standard range from CAD software to tools for specification writing, project management, product selection, building codes checking, and facility management. Initial prototyping of the concept-modelling paradigm in this context aims at improving the module for product selection that is used in the applications for architectural design and specification writing.

In two other research projects at Eindhoven University of Technology the usability of distributed object models is investigated.

The first project concerns the development of a method for evolutionary development of design alternatives subject to a set of performance constraints and user requirements. National and local building codes are regarded primarily as constraints that a building design must satisfy (van der Zee and de Vries 2002). These constraints are derived from national standards, developed by national standardisation institutes. They are often
subject to chances. In the distributed object model approach, the standardisation institutes would maintain constraint-objects and provide remote access to them. This way, conformance-checking applications can always use the latest versions of the building codes.

The goal of the second project is to develop an application that checks if a building is designed according to the local zoning plan. During the design process, the designer must have access to the latest version of the zoning plan. Vice versa, the local government needs to have access to the most up-to-date state of the building design, also after the construction of the building. For the latter purpose, authorities would not want to rely on remote access, but always have the latest data with respect to buildings, infrastructure, sewer systems etc., in their possession. Working with local copies that remain a more or less active relationship with the original data at its source, is one of the future developments planned in this ongoing research.

6. REFERENCES


Open Architecture for Site Layout Modeling

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ABSTRACT: This paper presents an overview of a computer-based site layout model and focuses primarily on the project setup phase. The developed model has four modules: user interface, database, project module, and layout module. Setting up the project in the proposed model is carried out by the project module, utilizing open architecture concept. The main advantage in the open architecture is to allow for the incorporation of user-defined objects if they are not readily available in the model. The objects required to define a site layout problem are clustered into three tires: 1) Site Objects, 2) Construction Objects, and 3) Constraint Objects. The model is implemented in a CAD environment using an object-based approach. The structure of each of the three tires is described, and the mechanism of object selection/creation for a site layout project is explained. The paper describes the components required to implement an open architecture for site layout object selection along with their respective environments. The developed model can be easily extended to similar applications such as floor plan design.

KEYWORDS: CAD tools, Construction sites, Model design, Open architecture, Site layout planning.

1. INTRODUCTION

One of the problems in modeling construction site layout is the diversity of acceptable solutions and lack of exact rules or methods to follow (Cheng and O’connor 1993). Previous surveys show site managers design the layout based on their experience, common sense and adaptation of past layouts (Rad and James 1983). Furthermore, a range of facilities can handle the same task, leaving even more options for site managers to choose from. Several factors are considered by designers in choosing a facility such as construction type, contract type, and project size and location (Hamiani 1987). Therefore, facility lists are justified by the uniqueness of the project.

Previous research works on site layout have mainly concentrated on the layout process and not the structure of the project setup and selection of temporary facilities. As a result the computer models have been programmed for a limited and/or fixed number of facilities, site conditions, or layout constraints (Elbetagi and Hegazy 2003, Mawdesley et al. 2002, Zhang et al. 2000, Harmanani et al 2000, Li and Love 1998, Philip 1997, Yeh 1995, Hamiani 1987). Consequently they can not readily be applicable to any site layout problem, but to the one they have been programmed for. On the other hand, it is impossible to identify and embed every item that is used on construction sites. Construction industry has an open nature and new methods and products are continuously introduced. To comply with this diversity, an open architecture for site layout models is proposed in this paper. It focuses primarily on the project setup phase of a previously proposed computer-based site layout model (Sadeghpour et al. 2002). The model has four modules: user interface, database, project module, and layout module. The focus of this paper is to explain the functionality and mechanism of the project control module. This module assists in defining the requirements of a site layout and setting up a new project.

2. OPEN ARCHITECTURE FOR PROJECT SETUP

The developed module utilizes open architecture in order to allow the creation of objects that do not exist in the libraries of the model. Open architecture utilized in this paper calls for the formation of general categories that host a number of entities relevant to the problem being modeled. Selection of categories is based on the intuition of the model designer respecting two principles: 1) within each category, the entities share the same attributes; and 2) the selected categories are adequate to describe and present the project being
modeled. The project module of the proposed model applies these principles of open architecture to site layout problem.

Three tires of objects identified for the proposed site layout models are: 1) site objects, 2) construction objects, and 3) constraint objects. Object-based concepts have been utilized to represent these three tires. Object-based approach strongly promotes the formalism of data typing and encapsulation of information. Contrary to the object-oriented approach, no explicit inheritance scheme is imposed in the object-based approach (Zamanian 1992). As a result, the proposed tiers are implemented as object classes, encapsulating their relevant attributes. These attributes include the geometric and non-geometrical data and knowledge. The three aforementioned tiers of objects are described in more details below.

2.1 Site Objects

Site objects include the definition of site boundary and objects that reside on site before the commencement of construction, and hence have a known location. Site objects affect the location of construction objects, and consequently the final layout. Some examples of site objects are trees, existing buildings, specially marked areas on the site such as “unavailable”, “unsafe”, or “hazardous”, water ponds, or life lines such as sources of electricity, water, or phone lines. Site objects often exist on site permanently, however their duration on site can be specified if needed. In spite of their impact on site layout, site objects have often been overlooked in previous layout researches except in few (e.g. Lundberg et al. 1989). Site objects have two main roles in site layout: 1) they occupy space on site, so the area they occupy is deducted from the total site land; 2) their topological relations with construction objects define the constraining rules and hence affect the final layout of construction sites. Site objects contain geometrical attributes such as location on site, as well as non-geometrical attributes such as duration on site. A UML representation of site object is shown on Figure 1.

2.2 Construction Objects

Unlike site objects, construction objects are to be located on the site and hence do not have a predefined location. Construction objects address a range of items that are diverse in nature including equipment, material, temporary support facilities, buildings, lay-down areas, working areas, and generally objects that have to be located on site. Similar to site objects, construction objects are represented by object class (see Figure 1). The structure of a construction object is similar to that of a site object with a set of geometric and non-geometric attributes. Specific characteristics of construction objects are modeled as additional attributes. As an example construction objects can be fixed or movable. Unlike movable objects, the location of fixed objects does not change during the course of construction once they are located. The main difference between construction objects and site objects is that the location of construction objects is to be determined. For this matter, construction objects have constraint attribute that points to a number of constraint objects.

2.3 Constraint Objects

The process of finding optimum location for a construction object is carried out under a set of rules. These rules are mapped into a set of related objects referred to as constraint objects. Constraint objects are designed based on the objectives of the layout. As a result, the model is not limited to minimizing traveling distance, but can define other objectives such as safety and security.
Constraint objects are as well represented by object class. The main attributes of constraint objects are “siteObjectName”, “relation”, and “constructionObjectName” (Figure 1). These properties have been designed in order to facilitate the creation of new constraints when needed. Each constraint is structured of three main parts: 1) constrained element; 2) a topographic relationship; and 3) constraining element (Figure 2). The constrained element is always a construction object to which the constraint is assigned. Constraining element can be either another construction object, or a site object, which constrains the location of the constrained element. As an example, a safety constraint indicates that the explosives should not be kept close to offices. Offices are constraining the location of explosives with the topographic relation of “not close to”. If the constraining element is a construction object, like a trailer office, the constraint object is called (C-C). On the other hand if the constraining element is a site object, like an existing office building on site, the constraint object is classified as (C-S) (see Figure 2).

Object-based structure inherently facilitates regeneration of the objects. To create a new object, an instance of its class object is generated. The graphical user interface (GUI) assists in the creation of the geometry of the object in a CAD environment. The built-in databases of CAD model store the geometrical data of the construction and site objects. Examples of geometrical data are the area and the coordinates of object’s footprints. Upon the creation of the geometry, the user interface prompts for the complementary non-geometric data, such as date of arrival to site. To facilitate user data entry a fill-in-the-blanks questionnaire is provided (Figure 4). As part of construction objects’ non-geometrical data, at this point constraint objects are as well selected from the library and assigned to the construction objects. Similar to construction and site objects, the model allows the user to define new constraint objects. The design of the constraint objects described earlier, facilitates the process of their regeneration. The first element is known by the model since it is the construction object for which the constraint is being defined. The second element is selected from a list of topological relations provided by the model. The selection choice for the third element consists of a list of all the construction and site objects involved in the project. Figure 5 shows the user interface for constraint creation process.

The defined non-geometrical data is then merged with the geometric data of the object from the built-in database of CAD system to form a record in the relevant library. This record is associated with the geometry of the object via an attribute handling mechanism that provides a link between

3. DATAFLOW IN PROJECT MODULE

To achieve the flexibility of open architecture in the proposed model, the project module offers the users: 1) a list of the ready-to-use objects from each category to select objects that are pertinent to the project at hand; and 2) an environment that supports the definition of new objects and modification of existing ones if necessary. This process takes place via a graphical user interface. The model maintains libraries for the three tiers of objects described previously: “site library”, “construction library”, and “constraint library”. Figure 3 demonstrates the functionality of the project module in relation to the libraries of the model when setting up a project.

Setting up a new project involves defining objects from the three tiers. The term define refers to selection from a library, modification of existing objects, or creation of new ones. Once an object is selected from a library, the object along with the knowledge and data associated with it are retrieved into the new project work place referred to as project palette (Figure 3). The user has the access to modify the object. However, if the required object is not found in the libraries, the open architecture of model allows the user to create a new one.

Object-based structure inherently facilitates regeneration of the objects. To create a new object, an instance of its class object is generated. The graphical user interface (GUI) assists in the creation of the geometry of the object in a CAD environment. The built-in databases of CAD model store the geometrical data of the construction and site objects. Examples of geometrical data are the area and the coordinates of object’s footprints. Upon the creation of the geometry, the user interface prompts for the complementary non-geometric data, such as date of arrival to site. To facilitate user data entry a fill-in-the-blanks questionnaire is provided (Figure 4). As part of construction objects’ non-geometrical data, at this point constraint objects are as well selected from the library and assigned to the construction objects. Similar to construction and site objects, the model allows the user to define new constraint objects. The design of the constraint objects described earlier, facilitates the process of their regeneration. The first element is known by the model since it is the construction object for which the constraint is being defined. The second element is selected from a list of topological relations provided by the model. The selection choice for the third element consists of a list of all the construction and site objects involved in the project. Figure 5 shows the user interface for constraint creation process.

The defined non-geometrical data is then merged with the geometric data of the object from the built-in database of CAD system to form a record in the relevant library. This record is associated with the geometry of the object via an attribute handling mechanism that provides a link between
an object and user-defined attributes. This is a two-way link which facilitates retrieval of the attributes of a physical object, or conversely, finding the physical object by its record in the database. An instance of defined construction and site objects is sent to the project palette, representing the requirements for the project at hand.

Once a new object is created, it is automatically added to the corresponding library. This eliminates duplication and redefinition of objects for different projects. It also supports the expansion and enrichment of the model’s libraries, and more importantly, gradually customizes the model according to design needs and preferences of its users.

The proposed model is designed to interact with users at both expert and novice levels. The first level provides the domain–knowledge expert with tools to enrich the model’s libraries. This allows planners to apply their individual problem solving strategies, and thus, directly contribute to the knowledge base of the model. This feature eliminates the traditional need of a knowledge engineer for acquiring and structuring the extracted knowledge, and hence decreases the risk of misinterpretation and incomplete acquisition of relevant knowledge. Based on the model’s status of knowledge, the project module provides less-experienced site planners with a decision support for defining the requirements of a site layout project.

Figure 3. Workflow diagram for initiating a site layout project.

![Workflow Diagram](image)

Figure 4. Data enquiry form for construction objects.

![Data Enquiry Form](image)
4. IMPLEMENTATION

A computer implementation has been developed, based on the open architecture concept described in this paper. Visual Basic for Applications (VBA) in AutoCAD® environment was used for programming. Microsoft Access® served as the external database to accommodate object libraries. VBA provides a seamless link between the model’s user interface, AutoCAD, and the database. AutoCAD was chosen due to being one of the most commonly used CAD systems, and its graphical capabilities, which facilitate data entry for objects.

Figure 5. User interface for constraint object creation.

5. SUMMARY

This paper presented an open architecture computer site layout model and focused primarily on project setup module. The objects required to present a site layout project were introduced and their structure was described. The representation of objects in CAD environment was briefly described along with the process of selection and creation of objects. The open architecture of the model allows for direct contribution of experts to the model’s libraries, which can later provide a decision support for less-experienced planners. Using an open architecture in the project setup phase makes the site layout model flexible and not limited, as in previous models, to a single project configuration.

6. REFERENCES


Preparing design to support automation and robotisation in construction

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ABSTRACT: To support automation and robotisation for construction, there are many requirements. A very basic one is the availability of the information about the building or structure to be constructed. The information may include the design of all the specialties in the building. The format of the geometry of the building elements should be in 3D. This can facilitate the construction simulation, planning and scheduling and rehearsal of the construction using robots.

The paper introduces a system which only concerns the part of the design that can be tailored to support the automation of the construction process. It is a system that uses 3D as its geometry data format which can integrate all the design in a proper form, supporting composition and decomposition of building elements arbitrarily according to the needs of construction process. It also supports group discussion and decision making.

KEYWORDS: Multidisciplinary design; design integration; design for automation

1. INTRODUCTION

To support automation and robotisation for construction, there are many requirements. A very basic one is the availability of the information about the building or structure to be constructed. The information may include the design of all the specialties of the building or the structure. The format of the geometry of the building elements should be in 3D. This can facilitate the construction simulation, planning, scheduling and rehearsal of the construction if using robots or other automatic machineries. With all the 3D design information and all other necessary information such as site layout, material storage, access path etc, the robots or other automatic machinery can be planned for collision avoidance and optimization to increase efficiency and reduce error.

The paper introduces a system which only concerns the part of the design that can be tailored to support the automation of the construction process. It is a system that can integrate all the design into a proper form, supporting composition and decomposition of building elements arbitrarily according to the needs of construction process. It also supports group discussion and decision making.

In the current practice in design, it is still far from being satisfied for automation and robotisation. Furthermore, the design process itself is complicated. There are a lot of requirements to reach an efficient, error free design by a geographically spread design team with different specialties. The system we developed is one step forward towards the need of automation and robotisation of the construction.

The system is called M3D [Luo01] which is a first time attempt to provide a higher level integration and communication tool for an architectural design team. The outcome of the system is a complete set of design data and all the related information of the building.

The focus of the system is the integration of architectural design with other specialties such as structural engineering, air-conditioning, energy supply etc. It intends to make early integration to explore design errors at early stages long before the construction. It uses a neutral 3D data format: VRML. It accepts any architectural or engineering design tools that can output VRML, DXF or 3DS format files.

M3D differs from simple application sharing which does not provide concurrent control and authorization of the cooperative design object. Application sharing requires all the partners use exactly the same CAD tool. In contrary, M3D aims at a wide communication between the current CAD tools as it accepts different formats.

M3D has a web based database with all the design project information stored for the use of all the phases of the building lifetime. It has direct interface with the online design editor. There have been efforts in the construction society to use virtual reality for visualization, performing walk-through of architectural design by animation.
However, the design itself is in 2D. The 3D model is roughly made for visualization only. The construction simulation, automation or robotisation always has the problem to produce the 3D models for its use. Therefore, due to the lack of detail of 3D models and the communication technology to transmit large scale design models, the building models in these applications often look too simple and naive to reach the real need of the industry.

With our system, such problem is automatically solved. The detailed models that can decomposed to whatever level of detail in 3D of the building are there as the center of the information in the system. The designs are in 3D by nature with all the details necessary for error detection and construction. The visualization is only a by-product since the buildings and their supporting elements are already constructed virtually from the very early beginning of the design.

The system applies virtual reality technique to the AEC at a higher level. M3D consortium introduces the 3D design technology for the whole design process from early conceptual design until detail design [Luo 02]. Therefore, it overcomes the problem of the existing VR application to AEC industry which can facilitate the use of automatic machinery in the construction process.

The system has the following features that can support the automation and robotisation of construction:

• 3D Design integration and decomposition from multiple sites connected by communication network – to form a sequence of elements for the handling of automatic machines.
• Support for cooperative working sessions – to form a working scheme and plan by experts located on different geographic locations.
• Automatic design verification – if adding the robots and machines as scene elements, the collisions can be checked.
• Storage and retrieval of integrated project information
• Full capability of manipulating 3D design information – facilitate the decomposition and reorganization of the building elements according to the need of applying automatic machines.
• Use of VRML, DXF and 3DS to interface with third party CAD tools – easy to cope with geometric models of the objects in the construction sites, robots and other machinery.

2. THE SYSTEM

The system is an application program that runs on PC platforms on each user’s site. It is a collaborative tool especially for architectural project integration, on-line discussion, editing and decision making. It supports simultaneous, real-time multiple users cooperative working through low to medium bandwidth and long distance networks. The system can be tailored to the need of construction planning by using automatic machinery. For cooperative information sharing and visualisation, it is platform independent that uses web browser for access [Luo01].

Typically, the system is for a design team for a particular project. The team members can be geographically separated. Each member machine has to install a copy of the application. Each site has the same applications as others. There is no central control of the system for the cooperative working session. Therefore, any member in the system can call for an on-line working session with other members. For information storage, there is a central site which equipped with a database. Figure 1. demonstrates a typical use of the system. When each team has its own design work done at some stage, the chief architect may call for a working session. The team members can connect themselves by an available communication network. They can input their 3D design to the global system from local files or from the central database. All the other members can see the integrated design at the same time. They can manipulate them, modify them during the working session. Upon discussion, some modification may be made and can be agreed by the members and approved by the chief architect.

For integration and on-line discussion, the VRML is used as the neutral format. It accepts design from CAD softwares for architectural design and other engineering design via VRML such as AutoCAD, MicroStation, 3D studio and others. Standard format DXF or VRML can input directly.
into the System. Otherwise, they can be converted to VRML using a converter, and stored into database or local files.

3. 3D DESIGN INTEGRATION AND DECOMPOSITION

One of the objectives of the system is to provide a tool to integrate the architectural design with the structure engineering design and all other design projects to form a global design which is ready for construction. However, due to different formats in different CAD tools and many other reasons, there are no integration tools for all the specialties with complete capability for manipulation, modification and visualization of the global design, particularly in a cooperative way. Actually, such a tool is under wide demand since an iteration of integration – verification - decomposition – integration happens all the time to produce a coherent, compatible and integrated project design. To use robots or other automatic machinery requires a very similar iteration and capacity of manipulation to the building elements. Based on such high demand, we developed a system with full capability required. All the teams can still design using their own favorite CAD tools. The only requirement is that all the design should be in 3D and follows our recommendation of design procedure and output the VRML format. Our online editor tool can accept input from local files, the database and the remote locations using the web addressing convention URL. Therefore, each team can use the system to integrate their own design first to form a specialty design. Afterwards, a global design including all the specialties can be formed by using system to work cooperatively. This integration process can be done online during a remote working meeting session or off-line.

As a strong support to integration and decomposition of the building elements in different specialties, the system organizes a global design as a 3D virtual scene with a tree structure. The users can decompose the design again easily in the design iteration for detailed design. During the working meeting, all the team members work together in a virtual design studio. They can manipulate, visualize the building elements as desired. The decisions made by the whole project can be saved. The integrated design can be decomposed again for further detailed modification by the authors of that part of design. A record will be produced of all the modification of the design for future reference.

The on-line cooperative editing mode is a working session connected by long distance communication network. The participants are able to upload their design for integration, discuss specific design problems, and modify it interactively. The off-line mode can be for the chief architect or project manager to prepare an on-line working session between the members of the team. It can be just a basic stand-alone tool for the architects and engineer.

The system is a multi-site, multi-user environment. A cooperative session can be held between two or more users, located in remote sites. The system allows concurrent manipulation of the design objects by multiple users. The system has been designed and implemented to be mutual exclusive for modification operations [Galli00]. Selection is the basic mechanism to assure mutual exclusion. This means that once an object is selected by a user, other users in the cooperative working session can not modify it until the object is released by this user. The local and remote selections have different color on the target object. The participants of the working session can easily see which object has been selected by other users. The editor also allows changing the working bandwidth according to the situation of the network during the session, making it scalable to several network configurations. A multi-user audio conferencing sub-system is also provided by the system [Luo01].

4. COOPERATIVE MANIPULATION OF 3D DESIGN OBJECTS

A team of architects, engineers and designers can work cooperatively during a remote discussion meeting using the system. The system supports on-line modification of the design. The changes made by any user will immediately appear to all the participants in the meeting. Modifying the position, orientation and scale for an object can be interactively dragging or exact numerical specification. The geometry of any single object can also be modified. Common functions in an interactive system, such as undo, and clipboard operations, can be performed. The major editing operations are: scene tree editing, geometric transformations, object editing, light management, material editing, and texture editing etc. There is a window specially showing the current design tree by names of the components. All the components are organized by specialties. This graphical textual tree can be edited by dragging its
nodes around. This makes the decomposition of the design easier. The objects can be selected from the tree using their names. This is proven to be very useful since there are usually large amount of objects in one design 3D scene. Furthermore, this allows the user to select a group of objects by selecting their parent node on the tree.

Figure 2. The textual window of the design project

A group of manipulators are provided for the interactive transformation. Dialog box is provided for numerical specifications.

The object editing option in the editing tool allows the user to isolate a particular part of the design and make other modifications on its geometry other than applying transformations.

The system provides the illumination options to the scene for visualisation and lighting test. The material of an object can also be assigned and editable. This can allow the user to specify and modify the material color, roughness, and transparency of the objects for rendering purposes.

A library of textures for the visualization of the architectural objects is provided. The operation of assigning or modifying the texture of an object can be performed locally or cooperatively.

Figure 3. A view of the material editor of the system

5. DESIGN VERIFICATION

According to our study the errors within these iterations can be classified in two cases. [Dias 99]. The first case is the omission of geometry information, which can cause indeterminacy. The second is the contradiction of the geometric information when two or more incompatible elements occupy the same space at the same time.

Our system provide a design verification tool which aims at solving the second type of errors. The specific geometric elements that can be verified include architectural and engineering objects within the same specialty project or from different specialties. For example, the verifier can check different classes of objects belonging only to the structural project, such as columns against beams. It can also verify between classes of objects from different specialties, e.g. columns from structural engineering, against walls from architecture.

With minimum extension, this feature can cope with the need in using automatic machineries in which the conflict in the robot path with the building elements can be checked during the simulation phase.

6. ARCHITECTURAL INFORMATION VISUALIZATION

Designed specially for AEC users, the system has rich options to visualize the architectural 3D design information through our 3D editing tool. The organization of the global design is intuitively visualized by a tree structure in graphics and text form, see Figure 2. The textual window of the design project.

Each individual building element’s properties and other information can be visualized as well. An object can be identified by a standard color code in our system. The editor follows the ISO 13567-1,2 standard to code each of the building elements. Object codes can be visible or hidden. Other object properties include the dimension of the object, the material etc.

For on-line interactive discussion and examination of the design, each individual participant can make navigation into the 3D models. Every user is represented on the screen by an avatar. The users can also visualize other participants' views in the cooperative session. A 2D map of the design scene is provided to avoid user's disorientation in navigating in 3D. The user can locate himself to any location in the 2D map of the design while his
3D view will appear on the 3D viewing window. The user can change his position and orientation either on the 2D map or on the 3D viewing window.

The system supports typical architectural viewing orientations and multiple windows. One can choose the point of view or specify it explicitly. To facilitate the visualization of the focused area, the objects can be hidden or visible. Clipping planes are available for any orientation to visualize the sections of the design. These sections can easily be interactively manipulated.

A measurement facility is also provided by the editor to give the user an exact knowledge of the dimension and distance of the object.

Figure 4. The 2D map

Figure 5. An arbitrary oriented clipping plane of the building

Figure 6. Definition of clipping parameters

Figure 7. The measurement tool

To improve the communication between the partners in the session, the editor provides support for textual annotations. The users can make a text annotation to any object in the design. Then they can be saved into the database for future reference.

7. STORAGE AND RETRIEVAL OF INTEGRATED DESIGN INFORMATION

As a complete solution to the problem we identified in the architectural production process, an integrated design project information storage and retrieval system has been developed. All information about other phases of the construction process can also be stored in the database. This may include the 3D geometry of all phases in design, the actual status of the project, photographs, preliminary drafts, proprietary CAD application data files, etc.

The advantage of having such an information system is obvious. All the information about a building project is stored from the very first beginning of the design phase. The information and its evolution history are always available for all the phases of the building object if desired. This can avoid duplication errors, wrong use of the design version during the design phase because the information system has the up-to-date unique copy of the design. It will facilitate the construction phase by providing a complete three-dimensional virtually pre-built building far before the construction. This can definitely be used for automation of the construction process [Luo02]. It can serve for maintenance of the building and even for historical archive.

The database can be accessed by a web-browser or within the editing tool. The users can search the design information using the structure of design projects such as design phases, design specialty down to a particular architectural object.
8. INTEGRATION WITH OTHER CAD TOOLS

The system uses the standard VRML so far as the native file format. It can open and insert any design in this format. Almost all modern CAD tools can generate VRML files as output. This means that the system can adopt whatever input from any CAD tools that output VRML format or via a converter. This is considered to be important since the traditional design needs a bridge to evolve to the new design business process. To provide such a bridge, the system can also accept DXF and 3D Studio files directly. Therefore, the design output from some dominated products such as AutoCAD can be input to the system easily.

9. CONCLUSION AND ACKNOWLEDGEMENT

The paper introduces a design integration system which may be tailored to serve the needs of automation and robotisation of building construction. It organizes all the design project information in a specialty based separation. It can compose and decompose a global architecture design from all the specialty design teams. With further improvement, it can serve for planning and scheduling of the construction process which is essential for the automation and robotisation for construction.

The work is a result of the M3D project in which the partners are: UIB, ADETTI, EDC, OA, IDOM and ARQMAQ. The European project funding No. 26287, the Spanish CICYT funding TIC-98-1530-CE and each individual partner’s contribution are acknowledged. See www.m3d.org for more information. Thanks also go to Toni Benassar who prepared most of the figures in this paper.

10. REFERENCES

Automatic Acquisition of Rules for 3D Reconstruction of Construction Components

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ABSTRACT: Aiming at the rule-based recognition system for architectural structure drawings, this paper presents a sample-based method that will automatically extract the geometric features of architectural objects and convert the features into recognition rules. When users designate the first sample of one type of objects, this method automatically analyzes and extracts the features useful for drawing recognition. Aided by a little interactive operation, recognition rules for this type of objects are generated. When a new sample of one object is designated through automatically comparing the new features and the old, this method analyzes and modifies the features of this object, then generates new rules. Along with new object types or new representations of old types are processed, rules of the recognition system are perfected continuously without modifying the program. This method can bring to the drawing recognition system higher self-adaptability and practicability.

KEYWORDS: Rule acquisition, architectural structure drawing, self-adapting recognition, construction component

1. INTRODUCTION

Although from drawing production to structural analysis, many aspects of architecture field have been computerized, some very complicated and tedious works have low automaticity. The production of bills of quantities is such kind of work. For each construction project, a great deal of time and manpower must be spent by the quantity surveying profession on reading hundreds or thousands of drawings, calculating and checking the result repeatedly. We have designed and implemented an architectural structure drawing (ASD) interpretation system (ASDIS), by which bills of quantities are conducted automatically and the work efficiency can be improved greatly.

Similar with many existing technology, our system chose to convert knowledge into recognition rules manually at first. Though this kind of static-rule-based methods can achieve good results, it also brings some drawbacks. Firstly, manual rule analysis is time-consuming and the adaptability of the recognition algorithm isn’t good [2-6]. Secondly, discussions are usually limited to symbol recognition. But for those complex graphic objects, the recognition ability is lower [4-6]. Thirdly, those methods based on object feature template are too closely related with the structure definition of templates. The recognition algorithm must be modified with the change of the template structure and the flexibility is low [2,4,6].

So some researchers had proposed ideas about automatic rule learning for drawing recognition [7,8]. But only a few actually implemented the learning procedure.

One class of these approaches uses decision tree. The values of one simple primitive attribute or dualistic relation (such as inclination) are collected through strict training of many samples. These values are the only basis for choosing cut points of the decision tree [9,10]. In addition, the user is allowed to decide which branches are more important and which can be deleted [11]. Thus, the tree structures are always very complex, lacking optimized path arrangement, and long traversal time is needed for recognition. Generally, they are only suitable for very simple graphics objects, such as “two cross lines”, “triangle” etc.

The other class is devised for classifying non-self-intersecting shapes that comprise straight lines only [12]. It analyzes conjunctions of local properties of each shape, indexes all the shapes by the properties and matches the indexed shapes against the instance by calculating the sum of the weights of successfully matched properties. Weights are manually selected and modified till all the samples can be recognized correctly. This approach needs a lot of samples and several different training sequences for one object type. Furthermore, it cannot adapt to objects with complex graphics (self-intersecting, or containing arcs, circles, strings) that appear frequently in architectural drawings.

To solve above problems, this paper presents a new heuristic sample-based rule acquisition method for self-adapting recognition system. This method introduces the combination of single-sample-analysis and multi-sample-comparison. Based on the integrated calculation of primitive attributes and relationships, supported by heuristic principles derived according
to general knowledge, feature extraction, reduction, synthesis and comparison are performed. Recognition rules are then converted from the features. Similar with human’s learning procedure, while more new object representations and types are being processed, rules are perfected step by step and the recognition effect improves. This method can deal with complex objects and has no special requirements on sample amount or training sequence.

2. SELF-ADAPTING RECOGNITION MECHANISM

Graphic primitives (GP) in ASDs can be classified into two groups: lines (points, straight lines, circles and arcs) and strings. One group of GPs, which has certain architectural meaning, is called “Construction Component” (for short, using object in this paper), such as “level symbol”, “column”, “beam”, “wall” etc.

2.1 Object Graphics and Corresponding Recognition Method

Different objects have different graphics representation characters, thus corresponding recognition methods are different too. Several typical examples are given as below.

1. **Topology matching**: Some objects’ graphics have fixed topology and the topology matching is used to recognize them. Fig. 1(a) shows one rectangular hole on the slab. Its size and aspect ratio change greatly according to the reality, but it has the fixed topology: “one rectangle contains two catercorner lines intersecting each other”.

2. **Leading GP matching**: Some objects contain one special GP fit for leading the recognition. Fig. 1(b) shows one level symbol, composed of one circle, two perpendicular lines and one string. Because the circle is usually a small part of all the GPs in a whole drawing, for improving the recognition efficiency, the circle in this symbol should be recognized firstly.

3. **Leading string matching**: Some object contain one string, which has particular composition rule and so can be the lead of the recognition. Solid lines in Fig. 1(c) compose one rectangular column’s boundary in the top view and dashed lines belong to the beams that are possibly connected with this column. String “C1” is column name, in which ‘C’ is the prefix, followed by one serial number. This is one of the naming rules of the column in ASDs in Hong Kong. String’s amount is also relatively small in one drawing and content-based string matching is fast, so when recognizing such kind of objects, for improving the efficiency, search the special string to locate the object firstly, then search other lines beside the string.

4. **String content validation**: Some strings in objects have no regular contents, so the lines must be recognized firstly and then the existence of needed strings is examined. In Fig. 1(b), ‘13.4’ is the string denoting the level value of the level symbol. This string must exist but the value cannot be forecasted, so it will be searched after the lines are recognized.

5. **Connectivity judgment**: Some objects are connected with non-object graphics by particular GPs. Such relationship must be validated after recognizing the object graphics. Dashed lines in Fig. 1(c) shows a kind of flexible relationship because the quantity and position of them are changeable. Dashed lines in Fig. 1(d) represent two objects connected with the beam “2B23”. They must appear around the beam and indicates a kind of fixed relationship.

6. **Exclusivity check**: If one object is not permitted to connect with any other objects or its graphics is a part of another object’s, exclusivity check is needed. Fig. 1(e) shows one dimension. It can be looked as two level symbols, one of which there’s no string. If one level symbol is found, additional examination should be done to confirm there’re no another level symbol (without string) existed beside found one, viz it isn’t a dimension.

7. **Group feature analysis**: Some objects contain GPs that can be classified into several groups. Each group embodies one kind of pattern –
quantity of GP is variable but arrangement is regular. The recognition method is the pattern matching aided by regularity checking. Fig. 1(f) shows steel bar structure in section view of two columns (strings are removed). One polygon of outer layer represents the column boundary, within which the steel bars are represented by smaller polygons, short lines and small circles clung to them. This regularity then is used for recognizing such kind of objects though the quantity and position of these steel bars will change greatly with the column’s size and shape.

2.2 Self-adapting Recognition Mechanism

Graphics representation characters of objects determine their recognition methods. But objects of the same type may have totally different shapes if applied drafting conventions or even only the draftsmen are different, so it’s impossible to forecast what kinds of representations will appear. Therefore, predefined object templates are always inadequate and the recognition algorithm then needs to be modified manually when meeting new object representations. This situation reduces the practicability of the approaches.

This paper presents a self-adapting architectural drawing recognition mechanism with a brand-new rule acquisition method. In this mechanism, the function of object graphics analysis and rule definition, which was manually done before, is moved into the recognition system. Fig. 2 shows the module that implements the generation and modification of the rules.

Assume we deal with the objects of type T. When users designate the first sample of T the system analyzes it to extract out the graphics features. These features are confirmed only or partially modified by users according to their experiences, then will be reserved as the representative features of T and converted into rules for recognizing T. When users designate another sample of T, the system extracts features from the new sample, then compare new features with old ones. Through analyzing the differences, the system can automatically (interactive operation can be done if needed) modifies the features and generates new rules that have better adaptability.

Along with more different object representations or types appear, the system modifies and perfects the recognition rules continuously, recognition module then can use new rules to achieve better recognition effect without modifying the program.

3. OBJECT ANALYSIS AND FEATURE EXTRACTION

Object feature, which in this paper means the geometric feature of the object, embodies a group of stable relationships among the GPs composing this object. Accordingly, recognition rules are the conditions judging whether the relations in object feature can be satisfied. Automatic feature extraction is therefore indispensable for later rule acquisition.

Fig. 2 Automatic Generation and Modification of Object Recognition Rules

3.1 Designation of Object Graphics

Given the sample drawing of one object type, following steps are needed:

1. The user draws a box to designate the object graphics and give the object type.
2. The user designates which are Connected Primitives (CP): the lines that don’t belong to the object but are connected/intersected with the object.
3. The initial feature, including all the basic geometric attributes and relationships of primitives, is automatically calculated and a simple preprocess is performed:
a) If CPs exist, then the object’s initial Connectivity is Fixed, otherwise is None.
b) If there’re other primitives around the object except CPs, then the initial Exclusivity is None, otherwise is All Exclusive.

3.2 Leading Feature Analysis

Every object has one most distinctive characteristic, from which the recognition can begin to achieve faster speed and higher accuracy. So we called it the leading feature. The leading feature may be one of following three types:

(1) Closed/Continuous Line Series (CLS), consisting of lines (arcs or a single circle) connected one by one, closed or open. Based on the initial feature data, all the lines are separated into one or several connected regions. Then in every region, all the CLSs (one primitive belongs to only one CLS) are extracted. Only four aspects of features are reserved for each CLS:
- Member primitives’ types and attributes.
- Relationship of neighbor primitives.
- Relationship of non-neighbor but self-intersected primitives.
- Filling pattern of Closed-LS: whether and how it is filled with some primitives appearing regularly.

(2) Object Name: a string having special composition rules, which are related with the domain or drafting conventions and are very difficult to analyze automatically. Column name is an example, see §2.1(3). So we present a method to define the composition rule by inputting a format-control string composed of predefined special characters. For instances, ‘?’ denotes digital numbers, ‘#’ denotes spaces. This method is also used for analyzing other strings.

(3) Critical Primitive (CrP): a special primitive except strings, whose size (e.g. line length) is the largest among the group of primitives of the same type. During recognition, if CrP is selected first, primitives smaller than it can be easily excluded.

Thereby, we analyze the leading feature as follows:

IF (object name was defined)
THEN according to predefined composition rule, extract the string as Leading String.
ELSE IF (Closed-LSs were found)
THEN classify them into several groups according to the following order: circle, polygon including arc(s), square, equilateral triangle, rectangular, ordinary polygon. The largest one in

the first group is defined as Feature Line Series (FLS).
ELSE IF (Continuous-LSs were found)
THEN Assign higher priority to Continuous-LSs containing more arcs. Among those having the highest priority, the one that has the most member primitives is defined as the FLS.
ELSE CrP of the whole object is Feature Primitive (FP).

3.3 Object Feature Extraction

3.3.1 Definition of Key Feature Group

After further reduction of the initial feature data mainly by the principles listed below, the object feature is synthesized into six groups with descending priorities. Together they describe the key characteristics of one type of objects.

Principle 1. Relationships describing the filling pattern of Closed-LS should be preserved.
Principle 2. Such relationships as endpoint-connecting, vertically intersecting, parallel and concentric, should be preserved.
Principle 3. For preserved relationships, those relationships that can be derived from them are omitted.
Principle 4. other relationships between two primitives, both of which do not belong to the leading feature, are omitted.

(1) Leading Feature (LF). It comprises four aspects:

a) Leading body’s type: can be Leading String, FLS or FP.
b) Leading body’s constraint: Leading String’s composition rules, FLS’s feature or geometric attributes of FP.
c) Matching constraint: describes how the leading body can be matched with the instance. Matching mode includes Topology, Direct, Scaled and Rotated. Valid scaling factor or rotation angle is also recorded.
d) Leading mode: can be leader-line leading, position leading and distance leading.

(2) Closure&Continuous Feature (CCF). If FLS is the only CLS in the object, then it is None, otherwise it comprises four aspects:

a) Structural constraint: geometric structure and size of each CLS.
b) Filling feature: None, or describes each CLS’s filling pattern.
3.3.2 Single-sample-based Initial Feature Evaluation

Features that are extracted from only one sample may not be integrated enough, but the initial values can be set automatically by estimation according to the general knowledge. For an instance, system will select “rotated matching [0-360d] plus direct matching” as the default value of TF, but “topology matching” as that of the matching constraint in CCF. Other examples include: position relation is the default value of relation mode; thresholds in all kinds of relationships are required to be “exactly equal” initially; etc.

Through automatic evaluation like above, obtained features may have some limitations. Users can modify manually according to their experiences to make the features more adaptable, or designate more samples to let the system modify the features automatically.

3.4 Multi-sample-based feature synthesis and modification

Generally, new samples are obtained by three ways:
- Manually selecting new samples in advance.
- During recognition, manually selecting wrong/missing recognized object as new samples.
- Automatically processing the object that is being modified interactively.

After processing a new sample of an object type whose features have been extracted before, the system compares the old features with the new ones and automatically modifies (also reminds the users to check) the object features according to the differences. Some primary principles are listed below:

1. If the old exclusivity type is “All Exclusive” but the new one is “None Exclusive”, then the latter one will be chosen.
2. If the old and new connectivity types are different, or both types are Fixed but CPs are different in type/amount, then the connectivity type is changed to “Flexible”.
3. With the change of positional relationship between string and line, relevant relation mode can be changed from “position relation” to “distance relation”, and the distance constraint value is changed. Similar changes apply to other constraints.
4. If the old CCF indicates one Closed-LS is Direct Matching, but in the new sample this Closed-LS’s size is changed but the shape unchanged, then its matching mode will be changed to Scaled Matching.
5. If the primitive composition of the new sample is the subset of the old, or vice versa, then only those features that are related with this subset of primitives are preserved.
6. If the new features are totally different from the old ones, both of them are preserved as coordinate features. For example, some CLSs appear in old samples but not in the new one, or the geometric structure is totally changed (Fig. 3). Then the common part (if exist) is extracted automatically and assigned with highest priority.

![Fig. 3 Examples of Feature Modification – Coordinate Features](image)
4. AUTOMATIC GENERATION OF RECOGNITION RULES

The recognition rules of each object type will be automatically generated or modified according to its current feature and recorded in the file with a predefined format.

4.1 Typical Object Recognition Process

Fig. 4 gives the typical recognition process and shows which group of features should be used for which recognition phase. If some features are lacked, corresponding phase can be omitted. That is, the recognition of one object depends on a group of ordered rules, each of which can be converted from some correlative object features.

4.2 Conversion from Features to Rules

Following are some examples.

1. Assume that leading type is *Leading String* whose composition rule is predefined as S (for example, S can be “B?#{(?X?)}”), leading mode is down-lead leading: ‘LL’, then recognition rule of *Leading String* is:
   
   IF MATCH_LEAD_STRING(S, ‘LL’)
   THEN RETURN(Names, Leading-lines)
   ELSE FAIL

2. Assume CCF indicates: one CLS’s structural constraint is described as the model (‘L’); filling feature is null (‘NF’); leading primitive is the longest line (a); matching constraint is *Direct Matching* (‘DM’). TF indicates “rotated matching” and permitted rotation angle is from 0 to 360: ‘T:R(0-360)’, then following rule is generated for recognizing this CLS:
   
   THEN RETURN(Polygon)
   ELSE FAIL

3. Assume CCF indicates: one CLS’s structural constraint is described as the model (‘L’); filling feature is null (‘NF’); leading primitive is the longest line (a); matching constraint is *Direct Matching* (‘DM’). TF indicates “rotated matching” and permitted rotation angle is from 0 to 360: ‘T:R(0-360)’, then following rule is generated for recognizing this CLS:
   
   THEN RETURN(Polygon)
   ELSE FAIL

4. Assume the exclusivity type is *All Exclusive*: ‘ALL’, then generated rule is:
   
   IF (TEST_EXCLUDE(‘ALL’) ≠ NULL)
   THEN FAIL

5. EXPERIMENTAL RESULT

Our method was experimented in ASDIS. Fig. 6(a) shows a corner of one architectural framing plan. It contains 7 types of objects including grid symbol, column, beam, slab-mark, hole, level-mark and section-mark. In the initial file, processing only the samples shown in Fig. 5 (1)-(7) generated rules for these 7 object types. After the first round of recognition, Fig. 5 (8)-(11) were chosen as new samples and processed using our method. As shown in Fig. 6 (b)-(c), the recognition effect using the initial database is not good, but becomes much better when the modified database is used.

For giving more detailed information, we take level-mark symbol as an example. Fig. 7 shows 3 samples and Table 1 then gives the content of the symbol features after extraction and modification through processing these samples one by one.
6. CONCLUSION

We present a rule acquisition method that can adapt to complex object graphics, brings higher applicability and self-adaptability to architectural drawing recognition system and is very useful in improving the productivity of the quantity surveying work. This method performs the heuristic feature induction from single sample and stepwise perfecting of rules through multi-sample-based feature comparison and modification. It need not be trained with a large number of samples and different sequences before the objects can be recognized. Our future research directions include investigating how to achieve feature reduction with higher flexibility.
7. REFERENCES


ABSTRACT: When we change a configuration by displacing or removing one object in it, desired adjustment of related objects usually follows established relational conventions. If, for instance, we displace a wall in which a window is found, we will expect the window to remain in the wall. At the same time we expect to be free to shift the position of the window in the wall without adjustment of the wall. This a-symmetrical relationship is one of Dominance. Relations of dominance are the main reason for structural and functional coherence. CAD programs may have ad-hoc performance of dominance, like with the window in the wall, but do not know the general principle, nor do they allow us to inform the computer about dominance relations we want it to maintain.

Sub-ordinate behavior drives the system. Dominant behavior results by implication. The methods defining sub-ordinate behavior are encapsulated in the object class. The designer determines the unique behavior of an object instance by specification of attribute values. Data input per instance related to class allows the computer to perform adjustments in an instance-to-instance chain, maintaining coherence of a complex configuration without need of global checking of relational data.

This paper demonstrates a notation and interface system by which dynamic relations, including those of dominance, between any two objects can be conveyed to the computer, enabling it, when properly programmed, to follow up adjusting when we design.

The paper further elaborates the concept of dominance leading to computer supported autonomous editing of a virtual building model as intended by the proposed interface and resulting in emergent coherent behavior of its constituent elements.

KEYWORDS: Design, Emergent behavior, Dominance relations, bi-directional editing

1. INTRODUCTION

In object oriented CAD application software objects belong to classes. Classes are parametric with attributes and attribute values. A specific object is an instantiation of a class. It has specific values given to the attributes (variables) of the class and may also include specific functions of the class. Classes may be simple primitives such as integers, real numbers or characters, more complex things such as vectors and text strings or may be very complex (high level) assemblies of primitives or even other classes. A high level architectural class may represent a door in a frame complete with hardware. The location of the object is determined by the coordinates of its local origin in relation to the origin of the database.

Dominance has been explained as a pervasive relationship among objects in complex configurations like the built environment. [Habraken 1998]. (See also 3.3 in this paper.) It is partly based on physical constraints like gravity and containment, but also to a large extent by convention of use and interpretation. The concept gives rise to algorithmic principles by which dominance can be ‘understood’ by the computer.

In general use in practice precedes programming; The interfaced proposed here illustrates the use of dominance relations and may also clarify the concept and stimulate its being incorporated in CAD programs. There are always many possible interfaces to deal with a certain design aspect. In this case we have tried to conceive of a simple formula to be used in conjunction with visual object representation on the screen.
The interface is bi-directional in that changes in a relationship between objects show in the formula bar, while changes in the latter activate changes in the visual representation. Where terminology is needed we have tried to keep it as close as possible to the practitioner’s experience, avoiding unnecessary mathematical vocabulary.

2. AN INTERFACE CONVENTION

2.1 Relations between objects

Given two objects in space, as shown in an on-screen design, a Distance Vector can be drawn from one object to the other. If drawn from A to B, it tells us about a relation of A relative to B. Many different Vectors can be drawn from A to B each giving another relational aspect. The length of a vector will be calculated by the computer and may be seen next to it on the screen:

![Figure 1. Relation of A towards B.](image1)

Once a vector is drawn, a formula will appear in a formula bar:

\[ A, B = 25 \]  

1)

If we change the Vector value to say, 20, object A will translate along the Vector towards B over a distance of 5. The Vector value can be changed in the formula as well as in the design. If we displace one of the objects, the vector and the formula will adjust. If we draw another Vector between A and B or between two other objects, the first vector will disappear.

![Figure 2. Negative vector value.](image2)

By convention, Distance vectors running outward from an object have positive values, those drawn inward across the object will be negative.

2.2 Sides of objects

To identify sides of an object in the formula bar, a convention of names for three pairs of opposite sides are proposed:

Head and Tail, Left and Right, Spine and Belly, or, respectively H, T; L, R; S, B.

For easy reading, a black dot will be shown at the head of an object when a Vector is drawn from or towards it. When the head is given, only one side of one other pair needs to be identified for all six sides to be known. For instance, when side L in figure 3 is identified as well as the head, all other sides are identified. We will be free to establish the sides of objects as we prefer, or to follow generally accepted conventions.

![Figure 3. Identification of sides of an object.](image3)

![Figure 4. Relations by means of sides.](image4)

Figure 4, for instance, specifies further figure 2, and will show in the formula bar as:

\[ \text{Ar, Bt} = (40) \]  

2)

Here the sides are written in lower case because they specify the relation AB. Instead of drawing a Distance Vector by hand, it can be efficient to let the computer choose a default Vector based on an orthogonal system, to be corrected later. Clicking on A first and B next would produce the Vector of figure 1. But now the formula gives us the sides as well:

\[ \text{Al, Bt,} = 25 \]  

3)

We could next alter Al into Ar, and obtain the Vector of Figure 4 with the (negative) length of (40).
2.3 Behavior profile (1)

In formula 3) we may replace the value of 25 with ‘x’, and we would get:

\[ A_l, B_l = x \]  

4)

The question mark asks for a specification of the constraints on x. Double clicking on it we get a window in which we may write, for instance:

\[ A_l, B_l = x > 10 \]  

5)

Saying in fact that the distance between the left side of A and the right side of B in figure 4 must be more than 10. This amounts to a statement of the behavior of A relative to B. The window contains the behavior profile of A. Relations of A to other objects may be entered there as well.

2.4 Internal relations

Once the sides of an object are identified, we can transform the object by moving opposite sides relative to one another. In figure 3, for instance, we can click Head and Tail, obtaining the corresponding default Vector:

[Diagram of Head and Tail with Vector 30]

Figure 5. Relation of sides of an object

While the formula bar shows:

\[ H, T, = 30 \]  

6)

This time the sides are written in capital letters because they are the objects in play. If we change the Vector value of 40 into 20, for instance, we will see the object shrink with H moving towards T because we have clicked H first. If we change formula 6) and write L instead of H, the computer knows relation LT makes no sense and will give us:

\[ L, R, = 12 \]  

7)

This is a general way to find out dimensions of objects and change them.

2.4 Dominance relation

If we want to establish a dominance relation in which A is to follow B, we must click A first and B later to obtain the default Vector of Figure 1, accompanied by formula 1). We next underline the formula obtaining:

\[ A_l, B_r = 25 \]  

8)

Meaning that we want A to maintain that distance when B is displaced or when the side to where the Vector points is displaced. If next we displace object A the Vector value will change (or the other way around.) But if we displace object B, we will see object A move as well to maintain its position relative to B. This is typical dominance behavior.

Suppose later in the design we return to objects A and B, but now we click on B first, we will see that nevertheless the Vector will point from A towards B. Because the computer remembers B dominates A, and we cannot move it relative to A. Similarly, when we have a window and the wall in which it resides in a dominance relation, we will only get vectors from the window towards sides of the wall. See Figure 6.

Once we underline a formula the computer will maintain a dominance relation between the two objects for any Distance Vector that may be drawn or given constraints, maintaining the full behavior of the subordinate object relative to the dominant object. Removing the underlining in any statement will render sub-ordinate behavior inactive.

2.5 Behavior profile (2)

[Diagram of Window in Wall with Vectors]

Figure 6. Window in wall

Suppose we now want to make sure the window stays within the wall. This requires a general statement about all possible relations between A and B. To make this, we click on A and B while keeping the shift key down, and get:

\[ A, B, = BP \? \]  

9)
In which BP stands for ‘behavior profile’ and the question mark indicates none is specified so far. To specify, we double click on BP and get a separate window in which A’s BP is to appear. We may type there, for instance:

\[
\text{Al, Bl, } = x \quad \text{and} \quad x > 0 \\
\text{Ar, Br, } = x \quad \text{and} \quad x > 0 \\
\text{Ah, Bh, } = x \quad \text{and} \quad x > 0 \\
\text{At, Bt, } = x \quad \text{and} \quad x > 0
\]

We may summarize this statement with a heading: for instance ‘inside’. Next time when we ask for the general AB relation we will get:

\[
A, B, = \text{BP ‘inside’}
\]

Without a summary title, only BP will appear, and by double clicking on it, the behavior profile window will open. With a summary title we can quickly see what is going on and, in a second case of containment, the designer can simply write ‘inside’ in the general formula to make two new objects relate in the same way. Readymade behavior profiles under summary titles may be available for the designer, who remains free to edit them. For instance: by changing the zero value in any of the four relations, the window may stay away a certain distance from the wall’s edge.

It may be that an object A is in relation with more than one other object. For each relation a BP can be written. When in such a case, holding down the shift key, we click on object A only, we get:

\[
A, = \text{BP}
\]

And by double clicking on BP we will get the behavior profile window of A, giving us the specifications and summary names of all relations A maintains in our design.

### 2.6 Relations between classes of objects

The database held by a CAD program yields lists of all kinds of object classes available in the object library. Referring to those, the designer may call for relations between classes:

Class A, class B, = BP? 12)

And may enter sub-ordinate behavior of A by underlining the formula, or specify the BP for class A. In this way relations may be settled for all high back chairs relative to all work tables and dining tables. Or for certain kinds of windows in certain kinds of walls. Instead of these functional relations we may distinguish classes according to levels of intervention [Habraken 1998] like, for instance, partitioning following a base building and dominating furniture, or buildings following the site, or a curtain wall following a steel frame.

A single instance of an object may belong to several classes and thus inherit a fully specified behavioral profile. Having access to the individual object’s BP, the designer can at all times edit it.

### 3. Algorithmic Aspects and Bi-directional Editing

Bi-directional editing implies freely editing of a CAD database both deductively and inductively, and freely analyzing and evaluating a CAD database. In the current art, CAD application software can analyze a database on the basis of user specified criteria, such as square footage, building cost, etc. To evaluate a database on the basis of criteria and values is a manual and iterative editing process. Our proposal implies a structured approach towards automating such evaluation processes.

#### 3.1 Objects

**3.1.1 Object Geometry**

The geometry of an object is specified by its morphology and topology. The morphological attributes qualify the shape. For example a curve. The topological attributes quantify the shape. For example the radius of the curve.

**3.1.2 Object Space**

An object has concrete space, which is the space filled by the object as a result of its geometry. It also has abstract space, which is the space required for it to function and the space required for the human user. For example the object geometry of a door is given by its height, width, and depth. Its functional space is the space needed for the sweep of its door leaf. Its user space may be additional space on either side of the door to allow access.

The total space that can be allocated to an object is the union of its concrete and abstract space. Functional space and user space alone can also be parametric classes. For example a corridor...
3.1.3 Object Intersections.

In a design it may be found that the spatial relation between objects includes both their concrete and abstract spaces.

The Distance vectors in our proposal allow the maintenance of abstract space and concrete space of an object. For instance by setting a minimum distance from the object’s concrete space to another concrete space or to an abstract space.

Relations will require editing. To automate such an evaluation requires that the geometric attributes of the abstract space are included with the parameters of each object. The nature of spatial relations may be an intersection of concrete space and another concrete space, concrete space intersecting with abstract space, and abstract space intersecting with abstract space.

3.2 Autonomous Object behavior

Behavior can be described as a deterministic system with in-put, through-put, and out-put. In a digital system these 3 phases would be: data transfer, data analysis, and internal data transfer to an encapsulated method. In the behavior sub-system the function of the data analysis phase is to determine to which encapsulated method the data should be passed. The encapsulated method may be an algorithm that edits the object geometry and/or edits the 6 parameters associated with the co-ordinates and orientation of the local origin within the Cartesian coordinate system of the model’s database and/or outputs data to a selection of objects. The data analysis phase makes the object autonomous and it seems to have a will of its own. On the other hand, if the data analysis phase is not included with the sub-system, received data is executed as instructed and object behavior is pre-determined.

3.2.1 Reactive agents

Attribute values about internal object space and global position can be transmitted as low-level data between objects. In that case an object behaves as a reactive agent (Nwana 1996) that gathers data: “pulling data,” and transmits data to a selection of other objects: “pushing data.” Reactive agents do not possess internal, symbolic models of their environment. They act and respond in a stimulus–response manner to the present state of the environment in which they are embedded. Objects react in basic ways to dominance and behave as reactive agents. Therefore dominant behavior of objects can be coordinated and implemented with relatively simple stimulus–response class algorithms. Complex patterns of behavior emerge from these interactions between objects when observed as group.

3.3 Dominance behavior

Relative behavior of objects can be symmetrical or a-symmetrical. With symmetrical behavior a transformation of object A results in transformation of object B and vice versa. With a-symmetrical behavior a transformation of object B may not result in a transformation of object A, but may induce transformation of object C. The concept of dominance as illustrated in this paper captures this a-symmetrical behavior. A-symmetrical behavior was implemented in 1999 while developing new prototypes of high-level objects for a library of parametric objects [Langelaan 1999] for ArchiCAD [Graphisoft]. For example, a change in the section width of a doorframe results in a larger total width and height of the door object, but a change in the total width of the door object does not affect the width of the frame but implements a change of the width of the door leaf.

Dominance relations can be identified in different contexts. Although not always obvious, they are mostly conventional and therefore can be generalized with editable Behavior Profiles.

3.3.1 Design Level Sub-systems

These are generally governed by scale and construction sequence. [Habrank 1998]. Customary design levels are those for Urban Design, Site Design, Building Design and Room Design. More recently, a Fit-out design level has emerged in commercial and residential building [SAR 1978]. Dominance between levels is fairly obvious from design experience.

3.3.2 Group Aspect System

Within each design level, objects with a common aspect can be related as logical groups, such as
mechanical, structural, electrical, egress, furnishing, storey, etc. Dominance is not obvious.

3.3.3 Class Aspect System.

This aspect system coordinates objects belonging to different classes. Class dominance is not obvious.

3.3.4 Custom Relationships

Design intention may lend sets of objects a relationship with custom dominance. For instance, object A always remains at the centre line of object B. Special geometric relationships could be specified with abstract relationship object classes.

3.4 Possible Applications

Capacity to deal in a systemic way with dominance relations allows new ways of computer supported editing and design development:

3.4.1 Fuzzy Choices

When the output of a logical process is discrete the process can be automated with Boolean algorithms. If a process encounters an array of possibilities whose choice is not stochastic neither objective nor decisive following iteration, but requires weighting and averaging then the logical process is fuzzy. At such occurrences an automated process must be interrupted and the question with its array of choices must be presented in an input window on the screen. For example questions about value sets of attributes, proportional relationships, dominance, etc. It must be noted that fuzzy logic reasoning algorithms may be possible to solve some of these problems.

3.4.2 Intelligent Editing

Intelligent Editing requires methods that maintain a geometric or positional relationship between discreet objects. The relationship can be inherited from the parent class or custom specified. The value of the relationship can be discrete “A on the centerline of B” or may be fuzzy “A near B” where “near” has the value set, near={min(n),max(m)}. For example, when the geometry or position of a wall object is edited, the related doors and windows remain embedded in the wall. Or if a kitchen cabinet is placed on a floor plan it will automatically position itself against the nearest wall.

3.4.3 Bi-directional Editing

Bi-directional editing of an object occurs when attributes that have a reciprocal relationship can be freely edited, and the values of the related attributes are automatically updated and implemented. Moreover, in sets of objects that have a reciprocal relationship, any object can be freely edited and attribute values of related objects are automatically updated and implemented. Finally, criteria can be selected for analyzing the model database; the result can be edited and attribute values of related objects in the database are automatically updated and implemented.

4. CONCLUSIONS

The proposed instrument performs in a uniform way a number of functions already available like certain groupings, containment, shrinking or stretching and translation of objects. In addition it adds important new aspects having to do with relational behavior including dominance.

In design, basic relations are rather simple, but relational chains can become extremely complex. With the proposed instrument coherent control of this complexity may become possible, leading to greater efficiency and smoother coordination among parties in control of different sub-systems.

The instrument will render the computer relationally intelligent and capable of tracing strings of adjustment in case of local design change to check on possible conflicts between sub-systems; list object space violations; evaluate dominance of listed objects and generally monitor and help control dynamic relations among objects.

Because relational data are connected by an instance-to-instance chain, control of complex configurations can take place without global checking of relational data.

With the help of this instrument, we may learn more about behavior of complex systemic organizations by exercise and research. This, in turn, may enhance our theorizing on form behavior in general and building design in particular, and may lead to automated editing of a virtual building model.
5. REFERENCES


Connecting 3-D Concrete Bridge Design to 3-D Site Measurements

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ABSTRACT: This paper describes the first results of an R&D project “Intelligent Bridge” carried out in Finland. The aim of the project is to develop new methods for 3-D design of concrete bridges and further connect and bring the design models to the source information of site measurements. A new design concept for 3-D concrete bridge design was developed and preliminarily tested in a pilot design office. The site tests of the first implementations of real time CAD/CAM measurements using a 3-D robot tachometer, as well as a 3-D laser scanning technique, are presented and evaluated.

KEYWORDS: Concrete Bridge Design, 3-D CAD, 3-D Measurements, 3-D Laser Scanners

1. INTRODUCTION

The total working process of concrete bridge design and construction is, even today, confused and ineffective. Participants in different phases of this working process use their own methods and tools, which operate, from the total process point of view, insufficiently, partly erroneously, breaking and delaying information chains, and the functionality of direct, effective and accurate refining chains. Considering it geometrically, a bridge element is a part of road geometry. The design process of bridge geometry is operated in a virtual road geometry environment. In Finland, concrete bridge design is mostly carried out using two-dimensional drawing-oriented AutoCAD software tools. At the same time bridge construction sites can already utilize different advanced 3-D measurement techniques. In this situation the required source information has to be planned in a separate working phase using manual user-specific design methods.

At present, design practice design documents, like drawings, quality specifications etc. are produced by 2-D CAD software applications. It is harmful that these design outputs cannot be directly utilized in construction measurements. Instead different human interpretations, format transformations and coding are needed to enable their utilization in site measurements and practical construction. It is clear that if bridge structures were designed as geometrical elements in the same 3-D site coordinate system, including, in addition to geometrical measurements, more intelligent information from the construction of these structures, better utilization of design information could be achieved. On the other hand, lots of different quality control measurements are executed and stored during a bridge construction project process. The results of these inspections are often given to the client without any visualization. If the quality inspection printouts are not introduced in an easy and understandable form, it is difficult to react to deviations and thus the aim of quality control is confused. Present 3-D design technology, however, enables visualization of these deviations.

The aim of this study is restricted to concentrate on this three-dimensional information connection between concrete bridge design and site measurements. The aim is to clear up the problematic field of 3-D concrete bridge design as well as the utilization of these design models in 3-D measurements on site. Different types of advanced 3-D measurement technologies are tested.
2. MODERN TECHNOLOGY IN SITE MEASURING

Ground-based 3-D laser scanners are offering a new technological possibility to geometric control on bridge construction sites. The determination and control of laser scanning accuracy is even today undergoing research and development. Santala and Joala have tested a new calibration method to determine the accuracy and uncertainty of the Cyrax 2500 laser scanner system. In these laboratory test conditions, and in the range of distance 0-50 m, the technical specifications of Cyrax 2500 for single point accuracy ± 6 mm (1 sigma) was verified. In practice, modeled surface precision is better than single point accuracy and equals to ± 2 mm according to the specifications. The consideration of the exact 3-D measurement accuracy for laser scanners is however a complicated research problem and remains to be further studied. [Santala & Joala]

Foltz has tested the Cyrax 2400 3-D laser scanner in a two-line bridge measurement (1999, Pennsylvania, Lemont, Spring Creek). The scope was, first, to capture a two-lane bridge, including steel and concrete structures, abutments, piers, road surfaces approaching the bridge, terrain under the bridge and adjacent areas, and second, to create as-built 2-D drawings of the bridge and adjacent areas as well as topographic maps of bridge approaches for export to MicroStation. With Cyrax a two-person crew needed three and a half hours to finish 13 scans from five locations to measure the total 3-D scene of the bridge. Compare this to traditional measurement methods: the same bridge was earlier surveyed with two two-person crews over a period of five days. To deliver the required 2-D plan, section and elevation drawings, 28 hours of processing time was needed, which was comparable to the estimated time needed with the traditional measurement and processing methods. [Foltz]

According to McManus, laser scanners have problems in their applicability to bridge measurements. In the measurements of a steel bridge with complicated surfaces and structures (Iron Bridge at Coalbrookdale, UK) both photogrammetric technologies as well as laser scanning ones were used. Finally, less than 1 % of the data in the final bridge model was from the laser scanner. The main reason for this failure was assessed to be the lack of direct edge detection. [McManus]

3. NEW 3-D DESIGN CONCEPT IN BRIDGE ENGINEERING

The basic idea in the new 3-D design concept is to utilize the same 3-D model through the construction process, Fig. 1. At the beginning, the designer creates a 3-D model and prepares all the design documents using the model, which is placed in the final position by using the terrain model and coordinate system of the project. The road geometry is specified by the road designer. The bridge designer can transfer the model to the analyzing program in order to make static and dynamic calculations. The designer completes the model by adding material specifications and tolerance requirements into it.

In the next phase, the model with other design documents is transferred to the client, who uses the information in the tender phase. Advantages in the tendering process are the speed of information transfer and the visual superiority of the 3-D model.

In the construction phase all site measuring is done by using coordinate data from the 3-D model in the robot tachometer, as well as a ground-based laser scanner. Only one surveyor with a movable computer is needed for the work. All information needed for measuring is included in the model. After the concrete has hardened, the as-built structure is measured and checked. The information is stored in the model and tolerance comparison is carried out by the special software. All deviations can be visualized.

Finally, when the bridge is completed and the contractor hands over the bridge to the client, all documents with the model are stored in the client’s maintenance system. Later on, annual inspection reports are attached to the same documents.

In the project, the new 3-D design concept has been developed and tested in three different bridge cases, Fig. 2-6. 3-D solid models for real bridges...
have been prepared. In the first bridge, (S44), the model was created by utilizing the 3-D terrain model, as well as the 3-D road model, as initial data. The second and third solids were created by utilizing the road models, only without terrain models. The CAD tool was MicroStation version 8. The solid model of the bridge was designed by extruding the cross-section along the 3-D road lines. The substructures were modeled separately. After modeling, the required 2-D drawings were prepared and printed out from the models according to the traditional working method.

Figure 2. The designed 3-D solid model of Pessankoski Bridge. The solid was prepared by extruding the determined cross-section along the 3-D road lines.

Figure 3. The final combination of 3-D digital terrain model, 3-D road model and 3-D bridge – designed solid model (S44 bridge).

The aim was to connect directly the 3-D design model to the 3-D measurements on site. In the case of bridge S44 the solid model was used both to measure and mark the points of steel pipe piles on the ground and later to control the achieved accuracy of the bridge. In the dimension measurements (Fig. 4) a 3-D robot tachometer (Trimble), as a device tool, and MicroStation, as a CAD tool, were used. The final accuracy of the dimension measurements (± 1 cm) was real-time checked by another independent Leica tachometer. For the tests of control measurements, two types of laser scanners were used. Using Callidus, as an example of “dome-like” scanners, two concrete deck slabs were measured, Fig. 5. Cyrax (fan-shaped scanner) was also used to measure the final shape of the slab, Fig. 6.

Figure 4. Connecting models to measurements - site tests of 3-D design model in real-time 3-D measurements using a robot tachometer as a measurement device (S44 bridge). The designed 3-D points of steel pipe piles according to the solid model were measured and marked on the ground.

Figure 5. Testing a “dome-like” (Callidus) 3-D laser scanner in the geometric inspection of the concrete deck slab of Pessankoski Bridge.
3. RESULTS

In the design phase the 3-D concept makes design work more demanding while a designer must be able to model the structures, which very often are curved, not straight. The raising of scaffolding is also difficult to process while the final shape of the structure is the most important. For 3-D design of concrete bridge solids, different additional tools are today under development. They are needed for such design tasks as: effect cross-section modeling, the extrusion of cross-section along 3-D road lines and the camber of a structure in measurements.

The first pilot tests have shown the visual superiority of the design concept. For instance, the geometry control survey of steel pipe piles can be visualized easily and the designer can reanalyze the pile system immediately after receiving as-built results, Fig. 9. In the construction phase, the connection of the 3-D design model to the site measurements makes it possible to measure and mark points and lines directly on ground or structure surfaces by utilizing the prepared solid model. While the real-time CAD connection can be used no transfer coding and formats are needed.

The second extension is that the designed 3-D solid model enables geometric comparison between measured dimensions and shapes, designed ones and tolerances. According to the tests, fan-shaped laser scanners seem to be more applicable to shape measurements of concrete bridge structures.
In the test measurements of bridge S44, in total, 14 scans and 2,5 million points were needed to form a model of the bridge. Including set-up time, the measurement work was carried out in one working day in the field (one person). In addition, about half an hour was needed afterwards to register multiple scans together and about three hours to create the adjusted model of the bridge, Fig. 7-9. In practice, it is essential to find the required views to capture points from every part of the bridge. The more views and scanner locations needed, the more time is needed for measurements.

4. CONCLUSION

In bridge engineering, the information chain of the digital terrain model, 3-D road and bridge design cannot be fully utilized yet. 3-D bridge modeling should be based on terrain and road models in order to ensure faultless bridge solutions. We can evaluate that the 3-D working method will generate benefits both to bridge design and site measurements. In addition, different effects and advantages on other functions in the field of bridge engineering are estimated and can be generated.

In control measurements the effectiveness of laser scanners seems to be essential (compare the results with Foltz). The analyzing software of measurement results should however to be developed. In software comparison tool of measured point cloud to designed 3-D model is missing until now. Also direct tolerance comparison is not possible with the present technology. Deviations should be directly and easily analyzed and compared to the accuracy requirements.

Based on this project, it can be estimated that electronic communication with electronic bridge documentation seems to be the next development in bridge engineering.

5. REFERENCES


Figure 1. The main process of the 3-D concrete bridge design-measurement system.
Intelligent Road Construction Site – Development of Automation into total Working Process of Finnish Road Construction

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ABSTRACT: Numeric road construction processes and their parts are today developed worldwide. This paper describes research in Finland, which is conducted with companies using national technology funding in a research and development project entitled "Intelligent Road Construction Site”. In its entirety, four public research projects and two product development projects are today ongoing. One development project has already been completed, producing a Finnish version of an automated 3-D blade control system of road grader. New projects are in design and starting. In total, there are four research units and 16 companies or other infra organizations carrying out these activities. The financial investment into this research and development is EUR 2 million for the years 2001-2005.

KEYWORDS: road construction, automation, 3-D CAD, 3-D measurements, 3-D machine control systems

1. INTRODUCTION

Different types of machines are used in earth moving tasks. In recent years, the effort in developing automated control systems for this machinery has been constantly increasing. One of the most important perquisites for this regeneration is the development of 3-D measurement technology. With the aid of robot tacheometers, mobile machines can today be positioned with a high degree of accuracy. Using the RTK-GPS measuring method it is also possible to achieve comfortable dynamic positioning accuracy. Again, real-time connections to the design phase and models are at present. Today, 3-D design models can be used directly in dimension and control measurement tasks on site. In the near future the aim is to connect design to control machines. The first implementations and tests have started also in Finland.

Around the world, automated control systems have been studied and developed for very different machines and working methods. Fully automated systems have not been presented in such projects. Mostly, the role and task of these control systems is to aid the operator and measure and document the work. As an example, the control system in an instrumented pile machine can be examined (UK), in which the operator is informed of the depth as well as the rotation speed of the auger. In Europe, the automation of pavement work has been studied in CIRC and OSYRIS projects. In the United States, different control systems for the measurement and control applications of excavators have been developed. NIST (U.S.A.) has studied the automated control and navigation of mobile vehicles, the 3-D control of cranes, 3-D laser scanning technologies, 3-D visualization methods and the new possibilities generated by them and their utilization in construction. The control systems of excavators have also been studied in Italy and Poland. In Japan, unmanned construction systems and their economy have been studied. The connection of CAD models to machine control systems have received surprisingly little study. [Ban], [Budny], [Madhavan], [Malaguti], [Mure], [Peyret].

Perhaps the best way to be familiarized with marketable automation technology is to visit international technology exhibitions such as INTERMAT (Fig. 1) and SAMOTER. According to our general observations, it is remarkable that at these exhibitions the amount of machine control systems for earth moving machinery has continued to increase. The most noticeable product presentations have been made by TRIMBLE, LEICA and TOPCON. At the INTERMAT’2003 Paris exhibition, different 3-D machine control systems were presented (more than ever before) and nearly in all of the most typical earth moving machine types that have been introduced.
2. THE FINNISH EFFORT IN R&D – INTELLIGENT ROAD CONSTRUCTION SITE

The aim of the project entirety “Intelligent Road Construction Site” (Fig. 2) was set up to develop the Finnish road construction industry towards the level of numeric and automatic working processes. The main objective is to model the numeric total working process of road construction. In subprojects, publicly used road and bridge design CAD programs, measurement planning software as well as 3-D measurement technologies are studied (the total process research, Fig. 2, University of Oulu, Construction Technology). The Construction Technology Research Unit has also evaluated automation possibilities and potentialities of the most used road construction methods in Finland. According to this research, automation has real potentialities for road construction. One goal is to develop a modular control system for road construction machinery (the MODU research, Fig. 2, VTT Electronics). VTT has developed and tested different hardware and software modules and the interactive communications between them. Based on the modular “technology pack”, differently applied numeric control processes and automation systems will be further developed in product development projects. These will include machine control modeling programs, positioning links for working machines, blade control systems and product quality control systems. The parts will be finally tested in actual construction projects on site.

In the domain of mechanical engineering 2-D and 3-D control systems are modeled and simulated for road graders, milling machines and excavators (the SIMULATION research, University of Oulu, Mechanical Engineering, Fig. 6-8). A study concerning wireless road construction sites is also in the ongoing work phase (Fig. 2).

In the “Intelligent Street” product development project a laser scanning technology has been experimented with as a process part in street design as well as whole town modeling processes (Helsinki). In the “Intelligent Bridge” product development project new 3-D design methods are to be developed. The detailed results are described in a separate paper. The aim of the project is to take 2-D bridge design into spatial modeling extents and also connect 3-D bridge models to control 3-D measurements on site. A study of the effects of automated machine control on the quality of road structure has also been started (Fig. 2).
3. SOME FIRST RESULTS

The blade control system of road graders is the first result of the Intelligent Road Construction Site entirety (Fig. 5). In the system the 3-D location and position of the blade is continuously measured by a robot tacheometer and several position sensors. Measured data is compared with the 3-D road geometry model. On account of a kinematic inverse solution the adjustment and control data for hydraulic work cylinders is calculated. All of the possible blade movement possibilities are at hand also in automatic control mode. The role of the system is to help and assist the operator. Full automation has not been the aim of this development. The road grader system has been tested in three motor road construction projects. The test results have been excellent. Achievement with the control system has increased 100%. The best-achieved geometric accuracy of road structure layers has been ± 1 cm. The development project of the next age of road grader system has been started (Road grader II, Fig. 2, Roadsys Ltd).

In the research concerning milling machines (Fig. 6-7) two different automatic control modes have been simulated and tested. The 2-D control mode has already been preliminarily tested on site. A product development project on a new smart 3-D control system is just now in its starting phase.

Excavators are very widely used machines in road construction. In the entirety of Intelligent Road Construction Site the research and development work of the control automatic systems for excavators have been started (Fig. 8). Excavators are used for very versatile and demanding tasks. To enable automated control using the CAD model, we need a totally new mathematical solution for total freedom of movement. According to the simulation models and tests, the development of this kind of control system seems to be possible.
More digging intelligence could be achieved by connecting different GPR radar measurement technologies to detect underground canals, pipes and other structures. These types of control systems have already been tested in other parts of the world. In such developments it is always essential to look for any benefits generated by new automated control systems. They could be, for example, the detection and localization of previously assembled cable lines to information of the operator, the geometrical control data for digging new excavations or automatic documentation of operated materials. The pay back period of a digging control system could be very short, for example due to escape of only one cut of pipe or cable line.

4. CONCLUSION

Intelligent Road Construction Site is the Finnish research and development effort towards functional earth moving automation. According to the first results, automation seems to have very great effects and possibilities in the processes of earth construction. It is essential that this, traditionally a very low-tech evaluated industry, starts to utilize the most modern and newest technologies and applications. In Finland this awakening has been expansive in the domains of Finnish infra industry, Finnish Road Administration, the National Technology Agency and also the Road and Transport Ministry.

The effects of road grader automation on the processes of road construction have been studied for two years in a real construction project: labor productivity has doubled and accuracy has been beyond any criticism. It has also been also essential to notice the exhilarating effect of the control system on the key operatives: the designer has detected to control machines by his design model; the operator has received a new smart grader, which has brought to common work some very interesting and useful properties. The appreciation of other operatives has also increased. Again the direct information link from design to site operations is a very essential point. We assume automation technology to be full of different possibilities in earth construction.

5. REFERENCES


Figure 1. The total information process of 3-D road construction – one description level.

Figure 2. Ongoing projects - the project entirety of Intelligent Road Construction Site. The Finnish effort in road construction automation development.
Applicability of Laser Scanning to the Measurement of 3-D Terrain Model for Street Design

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ABSTRACT: This paper describes the first results of R&D project "Intelligent Street" carried out in Finland. The aim of the project is to develop new measuring and design methods and tools for street design and construction. Usability and accuracy of laser scanning technology was tested in field-tests done in Itäreimarintie street pilot in Helsinki area June 2003. Implementations of measurements using helicopter based 3-D laser scanning technique are presented and evaluated. Terrasolid Ltd. software products for laser data processing was developed and tested in this project.

KEYWORDS: Street Design, Street Construction, Laser Scanning, Accuracy, Reliability

1. INTRODUCTION

Process of street design and construction is even today very time consuming and complex process because of numerous information sources, participants, design technologies and tools used in working process. Information chain in street construction process consists (Fig. 1) of measuring of source information, modeling source data, design, construction, quality control and documentation. Reliable and extensive source information of existent situation is basis to perform total process of street design and construction done properly.

Air borne laser scanning is widely used measuring method to develop existing topography for road design and construction process in Finland. The City of Helsinki has used helicopter laser scanned data for developing city plan since 1999. Laser scanned data has not yet been broadly used as source information of digital terrain model for street design and construction process because of still inadequate accuracy and partly undeveloped tools for these purposes. At the same time traditional measuring techniques as robot tacheometers and RTK-GPS devices as well as 3D-CAD tools are generally used in street design and construction process. Present practice demonstrates that laser scanning technology is clearly more effective measuring method for DTM measuring in fairly large new road construction production than traditional aerial photography or survey by tachymeter or GPS. The applicability of laser scanning technology to smaller street construction production is not yet confident. It is essential to carry out does laser scanning measuring achieve sufficient accuracy and economy as source information technology for street design process. For example, can kerb line be measured sufficient accuracy by this technology? Flying altitude and speed of helicopter in city area are limitations, which affects attainable accuracy of laser scanning measuring results. On the other hand laser scanned models (Fig. 2) can be developed for versatile purposes during street design process, for example visualization of designs.

All the required measurements should be performed with sufficient accuracy, adequate reliability and acceptable costs. We can determine the accuracy to mean the capability to produce errorless results. Reliability of measurement means the capability to maintain accuracy during measurements. Economy of measurement is defined as the proportion of the pecuniary advantages produced by the measurement to the measurement consists themselves. [Heikkilä]

Pereira & Wicherson (1999) has reported accuracy measurements of laser-DTM. The accuracy (RMSE) of the lasercanned DTM Z values was found to be between 4-9 cm. Huising and Pereira (1998) has tested Saab Top Eye systems accuracy.
Flat bare soil terrain cover accuracy (RMSE) was 10 cm and asphalt cover accuracy was 8 cm.

This paper describes the first results of R&D project "Intelligent Street" carried out in Finland. The aim of the project is to develop new measuring and design methods and tools for street design and construction. One of the reasons for this laser scanning accuracy study is that in Finland orderer's of the street designs do not yet have enough information about accuracy and reliability of laser scanning measuring method.

The usability of laser-data processing and modeling and street design software solutions of Terrasolid Ltd. were developed and tested in this project. Accuracy of laser scanning technology was tested in field-tests done in Itäreimarintie street pilot in Helsinki area June 2002. Produced DTM-data was used in pilot street design process.

In the study the following applicability criteria were formulated for testing:
- can the determined measurement tasks be executed by this scanning technique?
- is accuracy sufficient for the performance of the determined measurement tasks?
- is it possible to achieve adequate reliability in these measurements?
- can we consider the measurements to be economical?

2. MATERIALS AND METHODS

Laser scanning of the pilot street

The objective of the field test was to measure accuracy of helicopter based laser scanning data from 100 m altitude and on different surface types. Scanning mission was done with TopEye helicopter based system in June 2002. System was equipped with 7000 Hz scanner and 3056*2032 digital camera. Test resort was Itäreimarintie Street in Vuosaari and situates in sparsely inhabited area in eastern Helsinki. It is 1050 m long, curved street. In this measuring process Helsinki City Surveying department took care of GPS ground receivers used for helicopter positioning.

In modeling process TerraScan and Terra Match software's were used to classify and remove unnecessary points and correction of orientation parameters using automatic or semi-automatic rutines. Digital photos taken during the scanning flight was rectified by TerraPhoto software and photos was also used as aid in modeling process. This process was supporting the Finnish Terrasolid Ltd. software company's product development project. The product product family consists a group of solutions for different phases of infrastructure measurement and design process.

The main phases of modeling process were:
- Adjust overlapping laser scanned data strips
- Deleting erroneous points
- Classifying points by own definition (ground, low-, medium and high vegetation, buildings)
- Remove unnecessary points by thinning and rate of change in elevation
- Laser-DTM and digital photo data of Itäreimarintie-street was implemented as a result of modeling process.

Reference measurements

Reference measurements was done in four different cover surface. Survey was done as tacheometer measuring and it was realized by Helsinki City Street Department. First area is forest area near street resort. Second reference area is constructed area and third area is asphalt road. Fourth area is grass and partly sand field. Photos of the reference areas with some Z-difference measurement results are presented in pictures 2-5.

Accuracy of laser scanning was studied by comparing reference measurements with those at same locations derived from laser-DTM (table 1). The tachymetric measurements was used as Z-coordinate reference. The errors were grouped according to systematic and random errors. The comparison was made as an computation of root mean square error (RMSE) of the differences between the reference and the laser-DTM.
3. RESULTS

The results of the tests in measurement areas 1, 2 and 4 were that laser-DTM average systematic Z error was between five to ten centimeters above the ground. At first measurement results measurement area 3, asphalt road, average systematic errors sign was different than other areas. DTM of the area 3 was about seven centimeters below the ground, which gave a reason to distrust correctness of the measuring values. Flight strips in question was checked and the reason for deviation was found to be banking of the helicopter in that spot. After the failed strip data was removed, average systematic error was at same level as in other areas. Look results at table 2. After correction process average deviation of laser-DTM in all four areas was found to be 6.6 cm above the ground truth. Standard deviation (RMSE) of all test measurements was 9.1 cm.

Standard deviation of measuring results varied very little, from eight to nine centimeters, at grass field, asphalt road and constructed area. In forest area standard deviation differed others and it was 12.4 cm.

In this point of the study we do not have enough information to consider if laserscanning can be economical measuring method compared to traditional methods.

As a result of Terrasolid Ltd software developing work, new tools for TerraScan software was developed during the first half of this project. Most important innovation has been new semi-automatic building and roof modeling tools. There was also developed new algorithm to good effect. It can be used to identify for example kerb lines of street from the point cloud. In this project point density was not yet sufficient to use this tool to identify kerb lines.
4. CONCLUSION

On the basis of measurement results accuracy and reliability of helicopter laser scanning measurements was evaluated to be adequate for street design processes DTM-data. These accuracy results are parallel to Hyyppä & al (2002) measurement test results as well as accuracy reports reported by Huising and Pereira (1998). Reference measurements are still requirement to achieve necessary reliability for laser scanning.

Integrated laser scanned DTM and 3-D building models (fig. 6) is appropriate part of initial data of street design process.

In street renovation projects, which are situated in urban environment the usability of laser scanning in is not yet demonstrated. In this continuing project it is next aim to find out.

Developed software tools for processing laser scanned point clouds enable to model 3D-buildings with sufficient accuracy. Also bending lines of different structures are possible to identify by developed tools.

5. REFERENCES


Figure 1. The information chain of street design and construction process.

Table 1. Example of reference measurement results.

<table>
<thead>
<tr>
<th>Number</th>
<th>Easting</th>
<th>Northing</th>
<th>Known Z</th>
<th>Laser Z</th>
<th>Dz</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>62432.890</td>
<td>22940.310</td>
<td>3.895</td>
<td>3.925</td>
<td>+0.030</td>
</tr>
<tr>
<td>28</td>
<td>62424.860</td>
<td>22938.780</td>
<td>3.900</td>
<td>3.858</td>
<td>-0.042</td>
</tr>
<tr>
<td>29</td>
<td>62418.030</td>
<td>22937.890</td>
<td>3.912</td>
<td>3.865</td>
<td>-0.047</td>
</tr>
<tr>
<td>30</td>
<td>62412.340</td>
<td>22937.930</td>
<td>3.928</td>
<td>3.927</td>
<td>-0.001</td>
</tr>
<tr>
<td>31</td>
<td>62408.220</td>
<td>22939.950</td>
<td>3.894</td>
<td>3.847</td>
<td>-0.047</td>
</tr>
<tr>
<td>32</td>
<td>62406.200</td>
<td>22941.800</td>
<td>3.879</td>
<td>3.816</td>
<td>-0.063</td>
</tr>
<tr>
<td>33</td>
<td>62404.810</td>
<td>22938.760</td>
<td>3.874</td>
<td>3.679</td>
<td>-0.195</td>
</tr>
</tbody>
</table>

Table 2. Results of the test laser scans. In area 3 banking of helicopter caused failed measurement results (in brackets). After correction systematic error was at same level as in other areas.

<table>
<thead>
<tr>
<th>measurement object</th>
<th>average [m]</th>
<th>standard deviation [m]</th>
<th>points [count]</th>
</tr>
</thead>
<tbody>
<tr>
<td>area 1: forest</td>
<td>0.077</td>
<td>0.124</td>
<td>100</td>
</tr>
<tr>
<td>area 2: constructed</td>
<td>0.049</td>
<td>0.083</td>
<td>229</td>
</tr>
<tr>
<td>area 3: asphalt road</td>
<td>(-0.068) 0.043</td>
<td>(0.066) 0.087</td>
<td>79</td>
</tr>
<tr>
<td>Area 4: grass field</td>
<td>0.095</td>
<td>0.090</td>
<td>184</td>
</tr>
</tbody>
</table>
A Computer Aided System to Improve Dimensional Control of on-site Construction

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ABSTRACT: The increased use of prefabricated components, the complexity of new building shapes, and the speeding up of production in construction, demand an efficient and precise dimensional control. Meanwhile Information and Communication Technology (ICT) increasingly supports construction, among others, CAD systems and Total Stations, are being used for the purpose of dimensional control. In order to improve the dimensional control of on-site construction projects, this research tries to capture the knowledge required to design an adequate dimensional control plan and make that knowledge more generally available, and build a connection between CAD systems and Total Stations by applying state-of art ICT, focusing on prefabricated concrete building structural elements. This paper presents an updated information model that defines the various deviations and represents engineering experience knowledge using UML. The model has been implemented in a Dimensional Control System (DCS) and applied in the “La Tour” construction project in Apeldoorn, the Netherlands.

KEYWORDS: CAD Systems, Dimensional Control, Prefabricated Concrete, Total Stations, UML

1. INTRODUCTION

This paper is based on a research trying to capture the knowledge required to design an adequate dimensional control plan and make that knowledge more generally available, and build a dimensional control system (DCS) facilitating the digital connection between CAD systems and Total Stations. The research has been focused on prefabricated concrete building structural elements.

We have discussed the concepts of dimensional control and an initial model for defining various dimensional deviations in previous publications. Here we will focus on the update of the model and implementation of the DCS as well as its case study in La Tour project.

2. THE NATURE OF DIMENSIONAL CONTROL PROBLEM

The essence of dimensional control is to find out the points needed for setting out, positioning and dimension monitoring. In the beginning, one of the research objectives has been to investigate the body of knowledge used by the engineers to design the dimensional control plan. After observations on building sites and interviews with the engineers, contractors and site personnel, it is concluded that there is little explicitly expressed knowledge generally available. That is to say, there are no clear answers to the question of which points to be used for the different aspects of dimensional control including setting out, positioning and dimension monitoring and why. Also, in the Dutch standards for measures and measuring in construction (NEN series 14), the answer cannot be found though it gives some insight to tolerances and deviations.

There is however a lot of factual dimensional control knowledge that resides quite – in the form of rules of thumb – in the heads of experienced planners. On the other hand, there are so many forms of deviations and dimensional differences following different construction methods for various types of projects, that it is not reasonable to expect that the whole body of dimensional control knowledge will ever be fully formalized at all.

The dimensional control problem is basically of a stochastic nature, because every measure originating from construction process has a stochastic deviation and each solution first has to find a way to handle this. Handling the stochastic deviations originating from construction processes like prefabrication, setting out and positioning, is quite problematic for humans but ideally suited for computers.
3. POSSIBLE ICT SOLUTIONS FOR DC

We have studied the state of the art in ICT as seen relevant for the development of a DCS. The main conclusions are:

1) AutoCAD and Visual Basic provide the development environment most suitable for dimensional control (DC). Besides the fact that AutoCAD is market leader in design software of the building industry, it also provides an entrance to the world of Product Data Technology and related next generation tools. With the integration of Visual Basic, a simple but powerful programming language and application builder, it seems possible to build a DCS that can be accessible for the future users to add their own experience to the system. VBA is the programming environment most suited to the job, as it is able to work with a domain specific object model. This object model can be tailored to the needs of DC. Moreover with ADT also a product-modeling interface (IFC) becomes available. Finally there are several ways to import and export VR.

2) Knowledge Technology, especially Rule Based Systems, provides mechanisms suitable for DC to express engineering experience in the form of rules of thumb. Simulation and modeling are suited for prediction and calculation of error propagation of dimensional deviations. Fuzzy logic can be used to add greater flexibility to the expressions if linguistic ambiguity comes into play.

4. MODELING AND DESIGN OF A DCS

As mentioned above, there is very little explicitly structured and formalized knowledge available to be put in a knowledge base as a general solution to dimensional control problems. Dimensional uncertainty, dimensional deviation, and the stacking up of deviations springing from several sources form the core of the problem. Following the Monte Carlo simulation technique, we have a method to simulate setting out deviations, positioning deviations and product deviations, and the prediction of the dimensional deviation limits that show the dimensional quality. This method assumes that each individual deviation belongs to a certain range that has a certain percentage of certainty. For example, the deviation can be within the range of , 10mm ± with the certainty of 98%. Each deviation is randomly picked out of certain range and put together. If this is done a large number of times (e.g. 1000 times), the distribution of the total deviation can be predicted. On the other hand, it could still be possible to design a system capable of capturing rules of thumb when they come along.

Another observation has been that the DCS envisioned could also support experienced planners in complicated positioning situations. In fact the use of the DCS in complicated positioning jobs seems to be more attractive than the application of the DCS by inexperienced planners. The idea of this DCS is that a project database holds a detailed description of the facility under construction in a “neutral” (vendor independent) product model format. A product model described in the neutral format describes a facility (building, road, bridge) in the semantics of the construction industry. Product models can be exchanged or accessed by computer networks. The project database is filtered and converted by the DC-Tool to a local database that describes the facility as a collection of physical objects (structural elements, equipment and temporary structures) accompanied by coordinate systems and setting-out points. Next the positioning points are defined on the physical objects, using reference points, and the deviation and tolerance data is analyzed. The DC-Tool feeds the required control data to the Total Station on the construction site.

Based on the ideas mentioned above, we have updated our dimensional control information model by structuring the entities or objects needed for both the simulation of dimensional deviation limits and expression of engineering experience. Also example knowledge rules have been incorporated to the objects. This model is open and more knowledge rules can be added when available. See Figure 1 for the model in UML.

To implement the simulation, we need a random number generator (normal distribution). We have used the following formula to do the job:

$$\varepsilon = \sum_{i=1}^{12} R_i - 6$$

where the $R_i$ are independent random numbers between 0 and 1 ($1 \leq i \leq 12$) and $\varepsilon$ is the required sample from $\phi(0,1)$. This approximation can be used to generate variables of standard normal distribution with mean 0 and standard deviation 1.

To generate a normally distributed random variable $X$ with mean and standard deviation, the following formula is used:

$$X = \mu_x + \varepsilon \sigma_x$$

$\phi$ denotes the cumulative distribution function (CDF) of the standard normal variable.
In the implementation, the above-mentioned method has been used for generating random numbers of deviations that are distributed according to the normal distribution \( \mathcal{N}(0, \sigma_x) \). The range of each deviation variable can be determined according to standards (NEN series 14), and \( \sigma_x \) can be approximated from samples. When implementing the model into a prototype, we have chosen AutoCAD Architecture Desktop, Access and Excel as the software platform, and VBA as the programming language. The prototype can generate typical structural assembly or read an IFC format drawing. Figure 2 shows that the tool marks positioning points on an element when the user selects the element. For each possible positioning point of an element, 100 random numbers of normal distribution have been generated (Figure 3 shows the generated numbers in the Access database). The distribution of the predicted deviation limits, which is approximately the normal distribution, can also be shown in Excel. It also gives the X, Y, Z coordinates of the marked positioning points.

5. CASE STUDY

The purpose of doing case study is to test the model and prototype, and show the proof of concept. This can be done by using the prototype tool in practice to position several building elements and comparing with the traditional way in the aspect of position accuracy. The data has been collected on the construction site and analyzed in house. Then the conclusion has been made based on the data analysis. The office-building project “La Tour” concerns an office building with 21 floor levels. Around this building a parking garage of 3 levels will be constructed. The construction of this building will be going on as follows: foundation of prefabricated piles, cellar, in-situ casting concrete core by way of climbing formwork, prefabricated inner wall plates, floor slabs, and further façade elements which will be prepared as much as possible on the construction site.

5.1 Test

For this particular project of La Tour, the prototype developed before has been tested and improved. It functions as follows:

The GUI can read AutoCAD drawings of the floor plan and give advices on setting out the core construction horizontally and vertically by asking the user questions. The GUI first defines own coordinate system called RCS. This is because each drawing can have its own coordinate system and everything should be brought back to the same coordinate system. Then the GUI asks the user how many pours of floor there are and the sequence of pouring, and then it gives the number of MOUS points. The location of the MOUS point has relationship with the gridline, usually a fixed offset. Knowing the locations of the points, the system can add them into the floor plan. For vertical setting out, the MOUS points will be transferred upwards. The GUI asks the user to check for obstacles in the space with a range of 150mm. If obstacles are found, change the offset for everywhere and keep a safe offset; and also be careful with the distortion of signal/light. In the drawing of every floor, MOUS points have the same X, Y coordinate.

5.2 Collecting and Analyzing Data

The following steps have been carried out on the construction site of La Tour in Apeldoorn to measure and collect data.

1) Select two columns as study objects, one sloped and the other vertical (Figure 4 shows the sloped column on the site).
2) Put the reflecting stickers on two columns. On the sloped column, choose one side surface and find the practical center line of it (Figure 5 shows zooming in of the 3 stickers on the sloped column).
3) Put the reflecting aiming device on the two MOUS points and the reflecting sticker on the line of 1m plus.
4) Set up the tripod and the Total Station using Free Station method.
5) Choose “Free Station” in the software of the Total Station.
6) Sight the reflecting stickers on the sloped column and the vertical one, and measuring the X, Y, Z coordinate of each point.

The final position deviation of an object comes from the deviation of surveying instrument, the deviation of setting out marks including main control points and positioning marks for the object, positioning deviation, and the product deviation of the object. In this case study, the surveying instrument is the Total Station that has a deviation of 2mm in distance measurement and 0.0006g in angle measurement; the main control points are two MOUS points having a deviation of 2mm position; the positioning deviation of objects includes 3 translation and 3 rotation in the 3D space; and the product deviation includes...
deviation in 1D, 2D and 3D. We have analyzed the data by calculating the product deviations and positioning deviations for both the vertical column and sloped column. Figure 6 shows the sloped column with numbered points on one side surface.

5.3 Conclusions

The DCS has been applied in the case study by using AutoCAD drawing, Total Station plus storing device and stickers, whereas the traditional technique is paper, theodolite plus notes and measuring tape. Comparing the case method with the traditional technique, you get a list of advantages and disadvantages as follows.

Advantages of the DCS method over traditional technique:
- Speed and accuracy are higher because there are no intermediate points
- Reliability is higher because it reduces the chances of human mistakes by inputting data directly from computer to Total Station instead of paper notes
- It can work in 3D where traditional methods cannot
- It works very well with (pre)positioning of free form object in 3D
- Temperature independent
- It can reach NEN very easily

Disadvantages of the DCS method:
- Expensive as a start. Total Station costs NLG 18000
- People with higher quality of knowledge required

Weighing the advantages over disadvantages, the following conclusions on the DCS method can be drawn:
- Higher accuracy
- Less time consuming (around 50%)
- Highly profitable
- Can be used on all construction works

Therefore the case study shows that the method presented in the model and prototype of the DCS has big benefit for the construction companies if applied appropriately.

6. CONCLUSIONS

The conclusions have been summarized as follows:
1) The proposed simulation method and UML information model show a way to handle the dimensional deviations and structure the dimensional control knowledge in a computer interpretable manner. The implementation of a prototype of the DCS provides a digital way to bridge the floor plan design with dimensional control, predict dimensional deviation limits and output the data needed for a Total Station.
2) The case study tests the UML model and prototype of the DCS. The results prove that direct positioning of objects (by putting reflectors on the objects and using a Total Station and by inputting coordinates extracted and calculated from the AutoCAD drawings) provides higher speed, accuracy and reliability. It also shows a way to (pre)position a free form object in 3D where traditional methods cannot. This means that fulfilling the clients’ desire to increased freedom in shapes can be supported by the DCS.
3) With the development of IFC standards in the building industry, IFC based building modeling systems will replace current 2D drawing systems, which makes the DC system future proof.

7. REFERENCES

Figure 1. Dimensional Control Information Model in UML

Figure 2. Marking Positioning Points on an Element
Figure 3. Generated Random Numbers of Normal Distribution in Access Database

Figure 4. The Sloped Column on the Site
Figure 5 Zooming in of the 3 Stickers on the Sloped Column
Figure 6. The Sloped Column with Numbered Points on One Side Surface
Automation with or without ‘humanization’?
Dilemma in a developing construction environment

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ABSTRACT: In the present modern construction industry there is a growing acceptance for automation. Not only while the human need for it is growing or whatsoever, but also while the living environment in general is increasingly involved with automation-processes and equipment. See e.g. ICT-developments like mobile phones, internet, computers, household-appliances, etc. These daily ‘tools’ have been strongly integrated in day to day life and business. At least in the so called ‘modern society’. However, especially in developing areas the use of such equipment and technologies is still quite underscaled. That means that the way of behaviour of the people involved in daily life and business often is a pure ‘struggle for life’.

This paper focusses on the aspect of how to approach the ‘automation’ of daily life, especially in construction business as a means for improving construction productivity. More specific, focussing on an (underdeveloped but) developing environment. The dilemma of ‘automation’ or ‘labour-intensifying’ is discussed. In general it shows that the human component, i.e. culture and other human factors (here altogether called ‘humanization’) plays a more than just a role in it. It is a means which can help to overcome (practical) barriers on the path to better organized construction processes. Therefore, the question on how to get introduced a real ‘Future Site’ depends more on the level of human acceptance (barriers) than on the level of technological developments.

Although the approach presented in this paper is written mainly within the scope of construction in developing regions, it may also be used to rethink the situation of construction industry in modern developed regions.

KEYWORDS: Automation, Construction business, Environment, Humanization, Technology.

1. INTRODUCTION

During the last twenty-five years a strong increase of automation has been intensified. Lots of developments in construction were starting within this period. Think e.g. on new materials like high-strength concretes, special steel-qualities for high-rise buildings, but also e.g. corrugated-board products like boxes for homeless and beggars, etc. [Bats, 1994; Smurfit Lona, 1994]. However, these developments where gradually growing from ‘materials’ towards ‘processes’ (e.g. lean construction, etc.[Koskela,1993] and ‘tools’, e.g. robotics and IT, etc. [Cobb, 2001]). Especially these last mentioned aspects, the robotics and IT (tools) are of growing importance, as they act as (and influence…) the human-machine interfaces.

And that means that there are at least three key-issues:

- Environment (e.g. region, etc.);
- Humans (e.g. employee, etc.);
- Technology (e.g. equipment, etc.).

When looking to automation-issues a the means for improving construction productivity, it often seems the case that there is still ‘a gap’ between these two key-issues. This will be analyzed more into detail.

2. THE GAP: A FOCUS

Discussing about ‘a gap’ can lead to several ways of understanding. In general it means something uncompleted, or missing, or not finished or whatsoever, reflected on a sort of ‘bridge-structure’. Against the background of automation in construction, focused on the two key-issues of ‘humans’ and ‘machines’, this may seem a rather strange way of analyzing, as within ‘automation’ issues one may think first about machines, IT, etc. And that is not just the way how this paper is
looking at these issues. Automation starts in our approach with human beings. Such an approach does not mainly lead in our opinion to aspects of:

...how to make automation successful/effective/efficient in helping people.

But does more mainly lead to several aspects of:

...how to make humans successful/effective/efficient by using automation.

So, before ‘bridging gap(s)’ one should be aware of which gap(s) there are. Looking more into detail, in figure 1. this ‘gap’ is represented schematically, based on several fields of attention and leading thus to several ‘gaps’ like e.g.:

- Financial gap;
- Technical gap;
- Organizational gap;
- Cultural gap;
- Environmental gap;
- Etc.

Several of these gaps are obvious between each of the three mentioned key-issues, although there may be differences in level or intensity. However, especially the gaps related to ‘environment’ can differ quite a lot while this is in a global perspective a very diversified area, acting as the ‘playing ground’ for humans and technology in construction. See figure 1.

For reasons of embedding this topic within the activities of CIB-Task Group TG 23 ‘Culture in Construction’ (of which the author of this paper is a joint coordinator) combined with the attempt to make a more sharp focus, this paper draws special attention to the question how to bridge the

- Cultural gap.

Or more in general:

- Automation with or without ‘humanization’?

This, more specific in the field of human behaviour and related factors (here called altogether ‘humanization’), while the human factor in construction obviously plays an important role in problems, occurring during daily construction practice. Not only on a national level but also on an international scale; and not only in a ‘modern’ construction environment but also in a ‘developing’ construction environment [Tijhuis, 2002].

3. ENVIRONMENT: SOME DEVELOPMENTS

As in present industry the use of e.g. new technologies offers a lot of opportunities for improving construction processes and therefore should be stimulated if possible, it should in still be introduced quite carefully. This not only from e.g. a financial point of view (as e.g. Van der Schaaf mentions that such new technologies could be leading to cost-overruns in the first phases of introduction [Schaaf Van der, 1987]), but also and more especially from a cultural and/or sociological point of view, as e.g. the International Labour Organization (ILO) mentions that especially in case of developing areas, the use of labour-based technology is a serious means for local poverty-reduction [ILO, 2003].

Remarks:
Comparing the financial and sociological aspects of automation (see above e.g. the remarks of Van der Schaaf and ILO), one can see that these items often can lead towards a dilemma: Automation or not? And if yes, towards which level? etc. Nevertheless, it still gives interesting ‘food for thought’.
Related to this issue, it is being recognized on one hand that especially in developing areas the need for modern equipment is obvious while there is a strong need for fast improvement of e.g. local infrastructure etc. (being often in a bad situation), acting as an important means of stimulating local/regional economic growth. However, on the other hand this generally means that there are quite less possibilities for using local labour, e.g. due to the use of those automatized equipment, etc. *A real dilemma!*

This means at least that automation without paying attention to the ‘human factors’ will not be ‘the’ solution for improving construction productivity. At least not in areas which are not fully adjusted to ‘modern construction’.

4. HUMAN BEINGS: SOME DEVELOPMENTS

Being part of the human society, this society is a very dynamic one. Not only on local or regional levels but also on national and surely on international levels. Due to e.g. communication technology within the last decennia, the ‘influence’ of this globalization is getting more prominent: As a result, the role of information is becoming a key-issue for action and reaction in the present environment. Against these backgrounds everyone can see and experience that these global developments are influencing the local situation, leading towards a way of ‘glocalization’.

However, looking to these (technological) developments, the role of human communication still stays the most important thing in really doing business [Tijhuis, 2001]; at least to settle and restore good (business) contacts within personal (business) networks, apart from using tools like electronic communication and related issues. Within this point of view the human role with e.g. its personal *behaviour, training, skills* and *experiences* still stays in the centre of the ‘automatized’ (building) environment with developments in the field of e.g. *IT, electronics, mechanical tools* and *equipment*, as e.g. represented in figure 2.

Analyzing more close these automatized construction environments and the human role within it, one can distinguish more or less two main phases in construction automation:

- **Developing**
- **Implementing**

![Figure 2. Central human role in an ‘automatized construction environment’.

In the recent past, about ten to fifteen years ago, it seems that especially on branch and governmental levels there has been a strong emphasis on developing and just implementis without taking seriously care of the human factors (so ‘just automation’), at least in the Dutch situation. As e.g. described in proceedings of a Dutch construction automation conference in 1986, related to the governmental ‘Innovative Research Programme’ (IOP) for the construction industry, one can see that the topics mainly were related to ‘how to create an electronic building model or environment’, whereas there were also then some concerns that the ‘human factor’ is an important issue in *implementing* automation [Calibre et al, 1986]. So in the *development*-phase of automation there were no concerns…?!?

Just since about five to ten years ago there became more interest in human factors, due e.g. to the experiences that there were ‘missing links’ in automation processes in construction: Although implemented systems should be complete and functioning, people still had handling problems with it, leading to lot of failures (and costs!). These issues, together with e.g. an increasing need for transparency in construction processes, were recently some of the ‘drivers’ for the Dutch government to establish a new national research programme on ‘Process and System Innovation in Building’ (PSIB) [ARTB, 2002], being more or less a Dutch ‘counterpart’ to the British programme in ‘Rethinking Construction’ [Egan, 1998]. Human factors play an important role in it, as e.g. ‘Culture and Behaviour’ has become an own specific field of attention in this programme.
5. TECHNOLOGY: SOME DEVELOPMENTS

In modern construction industry several developments are actual. There one can see that on the ‘machine-side’ construction industry uses a lot of new technologies from other industries like IT (e.g. ERP or workflow-software), electronics (e.g. mobile phones), mechanical-engineering (e.g. TBM’s), space-technology (e.g. carbon/glass-fibers), etc. [e.g. EEIG, 1999]. On the ‘human-side’ it uses new approaches like ‘IFD’ [e.g. Hendriks & Van Gassel, 2001] but also ones which are not quite new anymore, but still under development and improving, like e.g. early ‘industrialization-drivers’ in e.g. early Post-World-War II period [e.g. Bromberg, 1947] and ‘open building’ since the 1960’s and 1970’s, etc. [e.g. Habraken, 1961]. And a lot of other developments can still be mentioned, like e.g. robotics in construction by using the fastest microprocessors and sensors, superlift-loads in offshore projects by using innovative jacking-systems, etc. Think e.g. about the recovery of the ‘Kursk’-submarine, etc.

6. THE CULTURAL GAP: PRESENT SITUATION

As global environment changes continuously, one should expect the continuous change of cultural aspects (i.e. human behaviour) within it, too. As this is still the case, a common state-of-the-art description of ‘the’ present situation on this ‘culture-topic’ is still very difficult, and maybe even impossible: As every human being acts according his or her character, mood, environment or whatsoever, and researchers still try to get a more ‘generalized’ view on it (for using the data e.g. in ‘predictive behaviour-models’), this really is a difficult task… But also very interesting, as construction still stays a ‘people’s business!

Remarks:
People involved in construction still stay the main factor of production, although productivity itself can differ (depending e.g. on the degree of automation, training and skills, etc.). Therefore, as construction industry still is the ultimate ‘people’s business’, the culture-issue within this paper focusses especially on the human behaviour of people, involved in construction projects; not trying to find an ‘utopia’ nor an ‘arcadia’ [Medawar & Medawar, 1972] but especially trying to get more understanding of reality.

Being able to understand culture (in this case human behaviour) can bring a lot more understanding for human uncertain factors within the construction process. Especially in an international scope, where the differences between human behaviour can cause really a lot of failure-costs (see e.g. the cross-cultural research on construction projects, related to difficulties into contracts, etc. [Tijhuis & Maas, 1996]).

As one of the representatives of this field of research and practice in construction, the already mentioned CIB Task Group 23 ‘Culture in Construction’ is assembling an international comparison on human behaviour in construction processes, both on theoretical and practical level. Firmly rooted into well-known research-results like e.g. Hofstede, etc. on the one hand [e.g. Hofstede, 1980; 1988], combined with (formats for) described practical experiences on the other hand, it seriously increases the availability and understanding of information on this specific topic [e.g. Fellows & Seymour, 2002]. However, within the scope of this paper, the author wishes to give at least a summary of the present situation in this field as follows: ‘Culture seems to become increasingly a part of the deal’.

7. BRIDGING THE GAP: AUTOMATION AND HUMANIZATION

The mentioned statement ‘automation with or without humanization’ in the title of this paper focusses on the dilemma which this may incorporate, especially in the described developing regions. However, putting it forward as a question indicates that it is often being looked at as a ‘duty’ to decide whether or not to pay attention to the human factors. And this often is the case: Fundamental research on robotics e.g. tries at one hand to imitate the way natural environments and humans act and react (e.g. with the development of fuzzy logics, human and artificial intelligence, etc.), and on the other hand is also fully aware that maybe other ways of robotic behaviour and/or mechanisms can be suitable for its designed takds, too. E.g. in this last situation, a robot may be even not being designed as a ‘typical robot’ (i.e. not a ‘look-a-like’ of a human being).

Remarks:

People involved in construction still stay the main factor of production, although productivity itself can differ (depending e.g. on the degree of automation, training and skills, etc.). Therefore, as construction industry still is the ultimate ‘people’s business’, the culture-issue within this paper focusses especially on the human behaviour of people, involved in construction projects; not trying to find an ‘utopia’ nor an ‘arcadia’ [Medawar & Medawar, 1972] but especially trying to get more understanding of reality.
See e.g. the differences between the ‘image’ of a robot, like e.g. in the 1950’s represented in science fiction comics, etc.: They were typical ‘mechanical human beings’, whereas in present days a robot can also be e.g. an extended computer, or a complex automatic control-system in traffic, or an automatized concreting or excavating machine, etc.

Main ‘path of decision’ in wether or not to use automation in construction stays the question of two main topics:

(1) whether or not using automation?

and if so, then:

(2) how to give the people involved optimized use of it?

Both of these topics are in fact based on the ‘interfaces’ between the three distinguished key-issues, as described in the start of this paper:

- Environment; Interface
- Human-beings; Interface
- Technology.

Both interfaces are represented schematically between the key-issues involved in figure 3, linked to the two main questions as described above. See figure 3.

So, bridging the gap between automation and humanization is still possible, but it should at least be committed to a positive answer to the both questions:

(1) Yes, there is an interface (e.g. fulfilled by -combinations of- need, relationship, matched way of behaviour, contract, etc.) between the human being an the environment (construction process, project, market-needs, etc.) involved;

(2) Yes, there is an interface (e.g. fulfilled by -combinations of- matched way of behaviour, fit-for-purpose, etc.) between the human being and the technology (automation).

Automation attempt therefore should start at least by means of the first step (1), with the search for how to fit the match between the needs of the environment itself and the human needs. The answer to this should result into a second step (2), with fitting the match between the human needs and the technology available. Therefore, the question on how to get introduced a real ‘Future Site’ depends more on the level of human acceptance (barriers) than on the technological developments.

8. CONCLUSIONS & RECOMMENDATIONS

As a result of this paper, the main conclusions and recommendations are represented as follows:

1. Before putting forward the question on how to implement automation in construction (i.e. focussing on the interface between humans & machines), one should be putting forward why to strive for automation construction (i.e. focussing on the interface between environment & humans).

2. If one has decided to introduce automation in construction, the level to which it should be integrated is an important detail. Especially while automation can be an alternative to labour-intensifying strategies, this means that
automation can be a stimulus as well as a threat to the people involved.

3. One should not ‘automatically’ assume that developing environments should only be improved by using the most modern and automation technology. It continuously should be the match between environment, human beings and technology.

4. The question on how to get introduced a real ‘Future Site’ depends more on the level of human acceptance (barriers) than on the level of technological developments.

Although the approach presented in this paper is written mainly within the scope of construction in developing regions, it may also be used to rethink the present situation in construction industry within modern developed regions.

9. ACKNOWLEDGEMENTS

For this paper several experiences from international construction processes have been used. More into detail, the author wishes to thank WT/Consult (www.wtprojects.com) for documenting and providing their experiences in the international field of construction industry.

10. REFERENCES

ARTB (2002) Quick Scan Bouwprocesinnovatie; Adviesraad Technologie Bouwnijverheid (ARTB); The Hague.


Bromberg P. (1947) Bouwen in Nieuwe Banen; NV De arbeiderspers; Amsterdam.


Cobb D. (2001) Developments on Automation and Robotics in Construction (ISARC 2000); paper; IAARC & Imperial College, London; Proceedings of CIB TG27; Wellington; Ed. Frans van Gassel & Ger Maas; CIB; Rotterdam.

EEIG (1999) EITO - European Technology Observatory 1999; European Economic Interest Grouping (EEIG); Frankfurt am Main.


Hendriks N. & F.van Gassel (2001) Construction of a Prototype of an Industrial, Flexible and Demountable Apartment Building System; paper; Eindhoven University of Technology, Eindhoven; Proceedings of CIB TG27; Wellington; Ed. Frans van Gassel & Ger Maas; CIB; Rotterdam.


Koskela L. (1993) Lean production in construction; summary from paper; Proceedings of 10th International Symposium on Automation and Robotics in Construction (ISARC); Houson, Texas; 24-26 May; pp.47-54; Elsevier Publishers; Technical Research Centre of Finland, Laboratory for Urban Planning and Building Design; Espoo.


Smurfit Lona (1994) *Corr Wall™ - Corrugated Board*; internal reports; product developments for construction industry; WT/Consult, Rijssen (www.wtprojects.com); Smurfit Lona Group, Loenen, The Netherlands.


A Multiple Criteria Decision Support Web-Based System for Sustainable Urban Development


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Abstract. The best sustainable urban development strategy of another country cannot just be copied. Strategies can only be adapted into a real economic, social, political, legislation/regulation and provision situation of the existing state. There is no such thing as a single sustainable urban development strategy to suit all societies and that could be applied to all countries. Based on the analysis of existing information, expert and decision support systems and in order to determine the best practice of sustainable urban development and to prepare recommendations for countries under consideration a Web-Based Sustainable Urban Development Decision Support System consisting of a database, database management system, model-base, model-base management system and user interface was developed. Studying the expertise of advanced industrial economies formed the initial database of the best practice.

KEYWORDS: Decision Support Web-Based Systems, Multiple Criteria Analysis, Sustainable Urban Development.

1. INTRODUCTION

Sustainable urban development is an information business. Technological innovation mainly through changes in the availability of information and communication technology inclusive calculators, analysers, software, neural networks, decision support and expert systems that have been provided by a variety of new services developed by the sustainable urban development sector. Most of all calculators, analysers, software, decision support and expert systems, neural networks seek to find out how to make the most economic sustainable urban development decisions and most of all these decisions are intended only for economic objectives. Sustainable urban development alternatives under evaluation have to be evaluated not only from the economic position, but take into consideration economic, institutional, environment, cultural, education, political, legal, social, management, technical, technological and other factors. Therefore, applying multiple criteria analysis methods and multiple criteria decision support systems may increase the efficiency of construction calculators, analysers, software, decision support and expert systems, neural networks and integrated construction on-line systems. Based on an analysis of existing the information, expert and decision support systems and in order to determine the most efficient versions Web-Based Sustainable Urban Development Decision Support System was developed by authors of paper. This system and the related questions were analysed in this paper.

2. CALCULATORS, ANALYSERS, SOFTWARE, NEURAL NETWORKS, EXPERT AND DECISION SUPPORT SYSTEMS

The major players in a sustainable urban development can use calculators, analyzers, software, neural networks, expert and decision support systems, etc.

A calculator is software application that is used for completing mathematical calculations. Calculators range from very cheap software, capable of performing basic arithmetical operations, to those whose capabilities extend to sophisticated mathematical and statistical manipulations and those that may be programmed with a large numbers of steps. Web sites [1, etc.] sometimes contain sustainable urban development calculators.

Interested parties also use software with various purposes as listed below: Rural/Urban Projection (RUP) Program [2]; atmospheric pollution, energy...
The major players in a sustainable urban development can use various purpose decision support systems. The decision support system (DSS) provides a framework through which decision-makers can obtain the necessary assistance needed for making decisions through an easy-to-use menu or command system. Generally, a DSS will provide help in formulating alternatives, accessing data, developing models and interpreting their results and by selecting options or analyzing the impacts of a selection. For example, Rylatt et al. [Rylatt] describes the development of a solar energy planning system, consisting of a methodology and decision support system for planners and energy advisers. Intended primarily to predict and realise the potential of solar energy on an urban scale, the system will support decisions in relation to the key solar technologies: solar water heating, photovoltaics and passive solar gain.

Expert systems today generally serve to relieve a ‘human’ professional of some of the difficult but clearly formulated tasks. For example, Onishi [Onishi] developed an expert system FGMS200 for integrated global modeling. The FGMS200 has been developed as a media of providing global information to the human society and finding out possibilities of policy coordination among countries in order to achieve sustainable development of the world economy.

Neural network is a method of computing that tries to copy the way the human brain works. A group of processing elements receives data and at the same time links are made between the elements, as the repeated patterns are recognized. A GIS-RDBMS-Neural Network-based system has been used for on-line consequence analysis of regional developmental proposals. The model outputs are used as the indicators of sustainable development [Khanna]. The feed forward neural networks have been used for hydrological modelling of run-off in Himalayan glacier basins [Buch]. Similar efforts in forecasting include river flow forecasting [Ichikawaet], and demand for electric power [Yuan]. Artificial neural networks have also been used as cognitive maps, e.g. in the application of aesthetic design of dam structures [Furuta]. The other important area of application is in the development of control systems for water and wastewater treatment plants [Cote].
technological and other type of information. This information should be provided in a user-oriented way.

The presentation of information needed for decision-making in the SUD-DSS may be in a conceptual form (i.e. digital/numerical, textual, graphical, diagrams, graphs and drawing, etc), photographic, sound, video and quantitative forms. The presentation of quantitative information involves criteria systems and subsystems, units of measurement, values and initial weights that fully define the provided variants. Conceptual information means a conceptual description of the alternative solutions, the criteria and ways of determining their values and the weights, etc.

In this way, the SUD-DSS enables the decision-maker to receive various conceptual and quantitative information on sustainable urban development from a database and a model-base allowing him/her to analyse the above factors and to form an efficient solution.

To design the structure of a database and perform its completion, storage, editing, navigation, searching and browsing etc. a database management system was used in this research.

The user seeking for an efficient sustainable urban development solution should provide, in the tables assessing sustainable urban development solutions, the exact information about alternatives under consideration as to the city’s financial situation. It should be noted that various users making a multiple criteria analysis of the same alternatives often get diverse results. This may be due to the diversity of the overall aims and financial positions of the cities. Therefore, the initial data provided by various users for calculating the sustainable urban development project differ and consequently lead to various final results.

The character of the objective’s choice for the most efficient variant is largely dependent on all available information. It should also be noted that the quantitative information is objective. The actual sustainable urban development alternatives have real costs. The values of the qualitative criteria are usually rather subjective though the application of an expert’s methods contributes to their objectivity.

The tables assessing sustainable urban development solutions are used as a basis for working out the matrices of decision-making. These matrices, along with the use of a model-base and models, make it possible to perform a multiple criteria analysis of alternative sustainable urban development projects, resulting in the selection of the most beneficial variants.

3.2. Research Methods Model-Base

In order effectively analyse database of best practice of sustainable urban development and to prepare recommendations for countries under consideration, it is essential to find the best research methods and analysis tools. The aim was to direct the research methods and analysis tools for assessing and implementing the goals of sustainable urban development.

Many decision making models and methods (multicriteria model [Nijkamp], a cost-benefit appraisal [Gallez], input–output analysis [Ferng], forecasting, quantitative and qualitative models and methods [Rotmans] have been developed in the world for solving the above and other problems.

The efficiency of a sustainable urban development variant is often determined by taking into account

![Figure 1. Initial data for integrated assessment for sustainable economic structures](image-url)
many factors. These factors include an account of the economic, institutional, environment, cultural, education, political, legal, social, management, technical, technological and other factors. The model-base of a decision support system should include models that enable a decision-maker to do a comprehensive analysis of the available variants and to make a proper choice. Since the analysis of sustainable urban development is usually performed by taking into account various factors, a model-base should include models which will enable a decision-maker to carry out a comprehensive analysis of the available variants and make a proper choice.

The following multiple criteria analysis methods and models as developed by the authors [Kaklauskas] are used by the SUD-DSS in the analysis of the sustainable urban development alternatives:

- A new method and model of complex determination of the weight of the criteria taking into account their quantitative and qualitative characteristics was developed. This method allows one to calculate and coordinate the weights of the quantitative and qualitative criteria according to the above characteristics.
- A new method and model of multiple criteria complex proportional evaluation of projects enabling the user to obtain a reduced criterion determining the complex (overall) efficiency of the project was suggested. This generalized criterion is directly proportional to the relative effect of the values and weights of the considered criteria, on the efficiency of the project.
- In order to find what price will make a valued project competitive on the market a method and model for determining the utility degree (see Fig. 2) and market value of projects based on the complex analysis of all their benefits and drawbacks was suggested. According to this method the project’s utility degree and the market value of a project being estimated are directly proportional to the system of the criteria and adequately describe them, the values and weights of these criteria.
- A new method and model of multiple criteria multi-variant design of a project’s life cycle enabling the user to make computer-aided design of up to 100,000 alternative project versions was developed. Any project’s life cycle variant obtained in this way is based on quantitative and conceptual information [Zavadskas].

According to the user’s needs, various models may be provided by a model management system. When a certain model (i.e. search for sustainable urban development alternatives) is used the results obtained become the initial data for some other models (i.e. a model for multiple criteria analysis and setting the priorities). The results of the latter, in turn, may be taken as the initial data for some other models (i.e. determination of utility degree). The management system of the model base allows a person to modify the available models, eliminate those that are no longer needed and add some new models that are linked to the existing ones.

This decision support system includes models enabling a decision maker to make a comprehensive analysis of the sustainable urban development variants that are available and then make the best choice for cities under consideration. The more alternative versions investigated before making a final decision, the greater the possibility to achieve a more rational end result. Basing oneself on a sustainable urban development database in one’s possession and the decision support system, it is possible to perform a multiple criteria analysis of sustainable urban development components and select the most efficient versions for the particular country. Strengths and weaknesses of the investigated sustainable urban development components also can be given in the analysis. Facts as to why and to what degree one version is better than another also can be established.

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the decision maker to receive various conceptual and quantitative information on sustainable urban development from a database and a model-base which allows him/her to analyse the sustainable urban development components and to end with an efficient solution.

Different countries have their specific needs as well as political, economical, social, technological, environmental, legal/regulatory and education situations. Therefore, every time countries use the sustainable urban development database they may make corrections to the database according to the aims to be achieved and the available situation. For example, a certain city considers economic sustainability to be more important than social sustainability, while other cities may be of the opposite opinion. The city striving to express its attitude towards these issues numerically may ascribe various significance values to them, which will eventually affect the general estimation of a sustainable urban development. Though this assessment may seem biased and even quite subjective, the solution finally made may exactly meet the requirements, aims and affordability of the city under consideration.

In this way we have a great number of potential stakeholders (urban developers, investors, providers, regulators, users, experts, etc.) of sustainable urban development which can employ of envisaged main deliverables.

3.3. Formation of Recommendations to Improve the Sustainable Urban Development in Lithuanian by Using SUD-DSS

The formation of recommendations to improve the level of efficiency of sustainable urban development in Lithuanian was included the following stages:

1. Identification and description of the present state of sustainable urban development in Lithuania and in developed countries:
   a) The formation of a system of criteria, characterizing the present state of sustainable urban development as determined by using experts methods;
   b) A description of the present state of Lithuanian and developed countries of sustainable urban development is given in a conceptual (textual, graphical, numerical, etc.) form and based on the above criteria system.

2. Comparison and contrasting of Lithuanian sustainable urban development with those of developed countries (see Table 1):

   a) Identification of the development trends and general regularities of the sustainable urban development in developed countries;
   b) Identification of the differences between sustainable urban development in Lithuania and in developed countries;
   c) Determination of the pluses and minuses of these differences for Lithuania today and in the future;
   d) Determination an efficient environment for Lithuanian sustainable urban development based on Lithuanian conditions.


4. Determination of effective solutions of sustainable urban development in Lithuania. The SUD-DSS’s model base allows for interested parties to identify areas where the Lithuanian situation is rational, average or is quite bad comparing with levels attained by developed countries. The data obtained, using this model base, can identify rational sustainable urban development trends in Lithuania.

5. Formation of recommendations to improve the level of efficiency of sustainable urban development in Lithuanian.

Table 1. Comparison and contrasting of the sustainable urban development efficiency factors in Lithuania and developed countries

<table>
<thead>
<tr>
<th>Countries considered</th>
<th>Information pertinent to development trends and general regularities of the sustainable urban development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quality of life</td>
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<tr>
<td>UK</td>
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<tr>
<td>Sweden</td>
<td>A2</td>
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<tr>
<td>USA</td>
<td>A3</td>
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<table>
<thead>
<tr>
<th>Countries considered</th>
<th>Identification of differences between sustainable urban development in Lithuania and developed countries</th>
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<tr>
<td></td>
<td>Quality of life</td>
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<tr>
<td>UK</td>
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<td>Sweden</td>
<td>D2</td>
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<td>USA</td>
<td>D3</td>
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</table>
Stage 3. Determination of pluses and minuses of differences between Lithuanian and developed countries sustainable urban development today and in the future

<table>
<thead>
<tr>
<th>Countries considered</th>
<th>Determination of pluses and minuses of differences between Lithuanian and developed countries sustainable urban development today and in the future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of life</td>
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<td>UK</td>
<td>$P_{i1}$</td>
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<tr>
<td>...</td>
<td>$P_{i2}$</td>
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<tr>
<td>Sweden</td>
<td>$P_{i3}$</td>
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<tr>
<td>USA</td>
<td>$P_{i4}$</td>
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</tbody>
</table>

Stage 4. Determination of an efficient environment for Lithuanian sustainable urban development based on Lithuanian conditions

<table>
<thead>
<tr>
<th>Countries considered</th>
<th>Determination of an efficient environment for Lithuanian sustainable urban development based on Lithuanian conditions</th>
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<tbody>
<tr>
<td>Quality of life</td>
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<tr>
<td>UK</td>
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<td>Denmark</td>
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<td>$E_{i6}$</td>
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<td>USA</td>
<td>$E_{i7}$</td>
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4. CONCLUSIONS

A variety of sustainable urban development automation systems have been analyzed to determine which processes are being supported on-line. The results of this study provide a useful insight into creating one’s own Sustainable Urban Development Decision Support System (SUD-DSS). SUD-DSS differs from others in the use of new multiple criteria analysis methods as were developed by the authors. The database of a sustainable urban development was developed providing a comprehensive assessment of alternative versions from the economic, institutional, environment, cultural, education, political, legal, social, management, technical, technological and other perspectives. Based on the above complex databases, the developed SUD-DSS enables the user to analyse alternatives quantitatively and conceptually.

5. REFERENCES


IFD Building Systems: a model simulating advantages of collaboration in the case of prefabrication in concrete

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ABSTRACT: A characteristic of the building sector is that different actors (responsible for design, production, construction, use) are separated by markets. Those markets hide a lot of information. As an example the production costs of prefabricated concrete elements are considered. One market strategy of a production unit of those components can be to search for profitable contracts without providing information of the real cost structure. Another strategy can be to offer designer insight in how major design options affect cost and to come to a win-win situation: better quality for end users and higher profit margins for suppliers. A prerequisite for this is that within the production unit a clear insight in the costs exist. ABC (=Activity Based Costing) can be helpful. Even more problematic is the integration of “cost-in-use” in the design process. Again the prerequisite is that cost information is available within the organisation in charge of running the real estate. If so the next step is that this information is made available for designers in such a way that the effect of major design decisions upon costs-in-use are transparent. An abstract model reducing the problem to the essence will prove that, even if modern information technology may improve the communication between actors, real collaboration requires transparent markets that can lead, provided good arrangements, to win-win situation for all actors involved.

KEYWORDS: Industrial, Flexible and Demountable (IFD), Building System, Activity Based Costing, Life cycle costing

1. INTRODUCTION: the atomised construction sector and holistic optimisation

A characteristic of the building sector is that different actors (responsible for design, production, construction, management and maintenance) are separated by markets. This separation is inherited from a period where the knowledge of building products available on the market (like bricks, cement tiles, …) or of production technologies for purpose-made-products (like wooden stairs or windows) was shared between all partners. With the introduction of industrialisation in the building sector first the concept of mass production and secondly variation based on a catalogue was introduced. Since housing has a much deeper impact on our lives than most other consumer goods the issue of end-user-control was raised soon. A major concept, becoming even more important in view of sustainability, was John Habraken’s proposal [Habraken] to consider two parts: the “support” and the “infill”. This concept, however, does not solve the problem of the elaboration of “supports” in collaboration between designers, producers and users. In this text only the case of concrete elements will be elaborated. IFD is interpreted as the production of “supports” in an industrialised way allowing different uses in the future in combination with the production of components for the “infill”. Also the “infill” should be produced in an industrialised way but on top of that allow dismantling and recombination. In this view there is no need for dismantling of the structure. This is, in view of sustainability the optimal situation: no dismantling costs, no waste, no recombination costs, no new inputs.

2. MAJOR PARAMETERS EFFECTING COSTS OF CONCRETE COMPONENTS

Cost information is, for most of the actors, a sensitive issue. Often markets are hiding the real cost structure for partners. As an example the production costs of prefabricated concrete elements is considered. One strategy of a production unit can be to search for profitable contracts without providing information on the real composition of
Another strategy, however, can be to offer designers insight in how major design decisions affect costs. The aim of this is to come to a win-win situation: better quality for users (more adaptability, larger units, more variation, …) and higher profit margins. A prerequisite of this is that within the production unit a clear insight in the costs exists. “Activity Based Costing” (=ABC) looks at the effect of certain characteristics upon the different steps of the production process and analyses how changes affect also “indirect” costs [Innes and Mitchell; Roztocki]. In the case of concrete elements the steps are: preparing moulds, making the reinforcement, fixing the reinforcement in the moulds, mixing concrete, purring concrete, applying finishes, transport and storage at the production site, transport to the construction site and fixing elements on site. A detailed analysis [De Troyer] shows that in most steps a large fraction of the costs are the same as well for small elements as for large elements (Fig 1).

This is for instance the case for manipulations (once the lifting equipment is available), the elaboration and consultation of production drawings, operations in the production cycle. The consequence of that for wall elements is represented in a graphical way in figure 1: for a fixed height the price per m² is decreasing in a hyperbolical way with the length. If those elements contain large openings the fixed costs per element have to be allocated to even less m², so the price per m² is higher.

If the manufacturer knows those effects upon costs, but only the price per m² (based on an element with average length and percentage of openings) is communicated to the designer, the last cannot include this information in his evaluation of proposals. All projects whereby elements have on average characteristics right from point A can be produced at lower costs than the average.

The gray area represents possibilities for a win-win situation. For all points on the lower boundary of the gray area the production unit makes the same profit as in the “average” situation and the end user benefits from the saving; for the points on the top boundary the profit goes completely to the production unit. Depending on the market situation and different contractual arrangements an intermediate position will be taken. One can expect that the average length of concrete elements will be larger in the case of “supports”. Also those elements will have fewer openings. In the present situation many small elements with a large fraction of openings are often produced (for toilets, bath rooms, circulation).

Designers, afraid that extra bending forces will increase costs, might reject the choice for “supports” with larger spans. In fact the basic law that, in case of uniform distributed loads, the
bending forces are proportional with the span to the power of two remains valid. But also in this case one should carefully look at the costs generated in each step. Pre-stressed hollow core floors have several advantages: reduction of weight, optimal use of concrete for resisting bending forces, high quality concrete based on production in a carefully controlled environment, etc.

Also in this case a large fraction of the costs are independent of the size of the element. Another part will increase with the span. For bigger cross-sections with more reinforcement the slope of this cost-in-function-of-span-line will be steeper. Again the cost per m² floor will follow a downwards-sloping hyperbolic curve in function of the span:

\[
\text{Cost per element} = \text{Fixed cost per element} + (\text{span} \times a)
\]

With \( a \) = constant for given section

\[
\text{Cost per m}^2 = \left(\frac{\text{Fixed cost}}{\text{span} \times \text{width}}\right) + \left(\frac{a}{\text{width}}\right)
\]

For uniform loads all producers of those pre-stressed floor elements provide “load-span” charts.

![Figure 3. Load to span chart for a single floor type](image)

This means that, compared to a design wit a lot of short spans, longer spans may almost not increase costs but create much more possibilities for adaptations to future needs. [De Troyer, Naert]

3. INCLUDING COST IN USE

One should not only look at the construction costs, but at the costs over the whole lifetime of the “support”. How adaptable “supports” will be depends on many factors like access, distance to the facades, location of equipment, … but for sure also on the size of the span. Larger spans will allow arranging spaces in different ways. Quantifying this in general is very difficult: small rooms designed to fit the original brief may be less appropriate if the family or organisation grows, if the way of living or working changes, if the property is sold to new users etc.
In this text only a simple model will be elaborated considering following factors:

- Basic investment
- Major adaptation costs
- End value of support
- Rental revenue

The return on investment (sum of the present values over the whole lifetime divided by the basic investment) will be compared for two cases: an adaptable “support” (subscript A) and a not adaptable “support” (subscript N). Numeric values used for the basic simulation are mentioned between square brackets.

General parameters are:

- \( i \) = general inflation rate (is also growth rate of rents) [2%]
- \( r \) = interest rate for present value calculations [5%]
- \( g \) = growth rate of construction costs; this is used for the evolution of the costs of major adaptation works and for the theoretical construction cost of the support at the end of the considered period. This reconstruction cost will affect the end value of the support [3%]
- \( n \) = number of years considered in the simulation; at the end of this period the support is sold or demolished [60 years]

- Basic investment
  
  The symbol \( f \) is used as the mark-up value for a more flexible support. Investment cost are represented by the symbol \( I \).
  
  \[ I_A = f \cdot I_N \]

- Major adaptations
  
  For the non-adaptable “support” no adaptations are considered. For the other “support” adaptation costs are expressed as a percentage \( (a) \) of the initial investment. In the simple version presented here the period in between adaptations \( (p) \) is constant and the lifetime is a multiple of this period.

  \[ \sum_{t=p}^{t=(n-p)} PV[A_t] = \sum_{t=p}^{t=(n-p)} a \cdot f \cdot I_N \left( \frac{1+g}{1+r} \right)^t \]

- End value of support
  
  At the end of the lifetime two possibilities are considered: (1) the “support” has still a certain value or (2) the “support” has to be demolished. In the first case this value is estimated as a fraction \( (e) \) of the investment cost adapted for the growth of construction cost. In the second case the demolition cost (to be paid by the owner or to be considered as a correction of the selling value of the land) is also estimated as a (negative) fraction \( (e) \) of the investment cost adapted for the growth of construction cost. So the same mathematical formula can be used.

  \[ PV[E_a] = e \cdot I \left( \frac{1+g}{1+r} \right)^n \]

- Rental revenue
  
  Annual hire is estimated as a fraction \( (h) \) of the initial investment growing each year with general inflation. In the case of a non-adaptable “support” the fact that, year after year, the construction is less suited to the evolving needs, is included in the simulation by introducing a depreciation factor \( (d) \).

  \[ \sum_{t=1}^{t=n} PV[H_t] = \sum_{t=1}^{t=n} h \cdot I \left( \frac{(1+i)(1+d)}{(1+r)} \right)^t \]

Parameters used for the basic simulation are summarised in table 1.

**Table 1: overview of parameters for basic case**

<table>
<thead>
<tr>
<th></th>
<th>Adaptable</th>
<th>Non adaptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment mark-up ( (f) )</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>Adaptation costs ( (a) )</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>Adaptation frequency ( (p) )</td>
<td>15 years</td>
<td>n.a.</td>
</tr>
<tr>
<td>End value percentage ( (e) )</td>
<td>40%</td>
<td>-5%</td>
</tr>
<tr>
<td>Hire percentage ( (h) )</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Annual depreciation ( (d) )</td>
<td>0%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

The “present values” of all the flows for this basic case are represented in Figure 6.
investment it is better to calculate the NPV per unit of capital invested. An overview for the adaptable type of the PV’s of the flows leading to this result can be found in Figure 7.

**Figure 7. Present value of the flows represented at the moment they occur**

The importance in present value of the adaptation works and of the end value is clear in a glance. An image showing how over the years the investment is compensated, is clearly pictured by a graph showing the sum of all the present values up to a given year (Fig 8).

**Figure 8. Sum of present values of the flows up to a given year**

The first flow is the basic investment (-1.200). The present values of the rental revenues are decreasing over time (Figure 6) so the curve of the sum of present values up to a given year is upwards sloping and the sloop is less and less steep year after year. In addition to that the graph is visualising the major adaptation works (= the downwards step every 15 years) and the positive end value in this case (= upwards jump at the end of the considered life time). In this case it takes 19 years before the investment is paid-back.

In order to compare with the non adaptable solution that requires a less important basic investment the “sum of the present value of all the flows up to a given year” is divided by the “absolute value of the basic investment”. This is represented in Figure 9.

**Figure 9. Sum of present values of the flows up to a given year per unit of capital invested**

Those curves always start from minus one. Since in this basic case the estimated hire is twice 8% of the basic investment the revenues in the beginning are practically the same. The rental revenue for the non-adaptable type is slowly decreasing (-0.5% a year). As a consequence the sloop is less steep compared to the rental revenues of the adaptable type. In the case of the adaptable type, however, the downward steps (due to adaptation costs) keep the curve below the curve of the non-adaptable case. The end value and end cost will invert the positions.

The first aim of this simple model is to present a way of analysing and representing the problem. This is a prerequisite before starting the discussion with actors involved. The next step is to analyse how sensitive the results are for certain parameters.

In table 2 all parameters are the same as in the basic case except the adaptation costs expressed as a percentage of the basis investment (a) and the depreciation of the rental revenue (d). This percentage indicates how the rental revenues will reduce year by year compared to a growth with general inflation. If inflation (i) is 2% and this depreciation (d) is also 2% the nominal rent will practically be constant: \((1+2\%)*(1-2\%) - 1 = -0.04\%\).

The “adaptable” case can be compared to the “non-adaptable” by calculating “NPV/Basic investment” for the two cases and divide the value for the “adaptable” by the one for the “non-adaptable”.

In the basic case \(a=15\%\) and \(e=-0.5\%) we obtain:
The ratio of the two is 1.11 as shown in table 2.

Table 2: Sensitivity analysis for “e” and “d”

<table>
<thead>
<tr>
<th>Annual depreciation (d)</th>
<th>0.0%</th>
<th>-0.5%</th>
<th>-1.0%</th>
<th>-1.5%</th>
<th>-2.0%</th>
<th>-2.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>1.05</td>
<td>1.29</td>
<td>1.60</td>
<td>2.03</td>
<td>2.63</td>
<td>3.53</td>
</tr>
<tr>
<td>10%</td>
<td>0.97</td>
<td>1.20</td>
<td>1.49</td>
<td>1.89</td>
<td>2.45</td>
<td>3.30</td>
</tr>
<tr>
<td>15%</td>
<td>0.90</td>
<td>1.11</td>
<td>1.38</td>
<td>1.75</td>
<td>2.27</td>
<td>3.06</td>
</tr>
<tr>
<td>20%</td>
<td>0.83</td>
<td>1.03</td>
<td>1.28</td>
<td>1.62</td>
<td>2.09</td>
<td>2.82</td>
</tr>
<tr>
<td>25%</td>
<td>0.76</td>
<td>0.94</td>
<td>1.17</td>
<td>1.48</td>
<td>1.92</td>
<td>2.58</td>
</tr>
<tr>
<td>30%</td>
<td>0.69</td>
<td>0.85</td>
<td>1.06</td>
<td>1.34</td>
<td>1.74</td>
<td>2.34</td>
</tr>
</tbody>
</table>

The advantage of the “adaptable type”:
- will be reduced if the adaptation costs will increase and
- will increase if the non-adaptability will be reflected in stronger reduction of the rents.

Important questions that can be simulated with the model are:
- How important is the estimation of the additional basic cost of the investment (f)?
- What is the effect if the additional investment in the adaptable type is not reflected in higher rents from the beginning, but the rents are equal to the rents of the “non-adaptable” type?
- Can the rents after each major adaptation be increased? How much? What is the effect upon profitability?
- Can an important tax on demolition or waste disposal at the end of the lifetime of the non-adaptable type change the picture drastically?

The simulations make it evident that feedback of cost information from organisations in charge of running real estate projects and from organisations active on the rental market is essential for taking the right decisions in the early design phases. Again a prerequisite is that cost information is available within the organisation and that contractual arrangements can be set up in order to come to a win-win situation: a better environment for the end user and higher profits other actors.

4. CONCLUSIONS

The separation in the construction sector between design, production, construction, use and maintenance is inherited from a slowly evolving area in the past. Optimisation is only possible if information is exchanged between different actors. Basic requirements are that the information is available within each organisation. On top of that arrangements have to be elaborated so that partners can benefit from making valuable information available for others: win-win situation. This principle is illustrated with two examples: information on production cost of prefabricated concrete elements and information on financial benefits of more adaptable “supports”.

5. REFERENCES


Dynamic Schedule Management Architecture Based on Parts and Packets Unified Product System

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ABSTRACT: In a construction project, although the completion day of the project is clearly decided, construction schedule is often changed by the weather or the actual progress situation of the project. Therefore, when a difference arises between present state and the master schedule, it is necessary to adjust the construction schedule and to execute immediately. Besides, since a construction project is usually carried out as a cooperative work by many companies, how to transmit information smoothly and how to share them together are an important issue. In this paper, the dynamic scheduling management system architecture that is based on the parts and information packets unified technology is proposed.

We assumed that each part or unit has a data career, which handle such as identification number, position of the part, state of the part. Some of them re used to define the part’s identity. They are given as the initial data, and are unchangeable and static for each part. Another kind of information is changeable and dynamic.

Using these data, progress of the project process is compared with the master schedule. If the difference arises between them, scheduling system derived the present workability of each section/machine/people and dynamically re-schedule to optimize the processes.

A pilot system that realized our proposal is developed and applied to a case study. As a result, the system can derive the changing state of section/machine/people and make the dynamic re-schedule by using the data originating in the part or unit.

KEYWORDS: Distributed System, Dynamic Scheduling, Parts and Packets Unified System Architecture, Production Process.

1. INTRODUCTION

A complicated production system is needed to satisfy by various requirements to production in recent years. The concept of an autonomous distributed production system is proposed as what can adopt to such circumstances. Numerous researches were done to construct intelligent and autonomous production system so far. Many of them focused on product facilities, and constructed intelligent system using network structure. By connecting with a network and communicating each other, each production facility can understand production status and can respond to the status. These methods are available when production facilities and products exist in the limited space like an automation factory.

On the other hand, the production system which production facilities and products are widely distributed like a construction production project causes problems by combining and communicating production facilities mutually. For example, status grasp cannot be performed on real time when the distance between the facilities is too long, or processing performed during the transfer between facilities cannot be grasped. In the case of the cooperative work by several different companies, it is difficult to combine facilities in a network.

Construction production differs from general machine production in that parts and units are supplied from different wide-spread fields and the component factories are also distributed.
geographically. It is difficult that an integrative system treats or utilizes each facilities’ information in such a production style. In recent years, IC tags which can store various data to parts are utilized, and can be used from a viewpoint of cost, size, and a function of communication. Therefore, the information about various production activities are given / read / written by using IC tags which stuck on parts, and the production system which manages the dynamic scheduling based on IC tags can be proposed.

2. CONCEPT OF PARTS & PACKETS UNIFIED SYSTEM

The concept of a dynamic production scheduling system using parts and packets unified architecture is shown in Figure 1. The IC tag is attached in the materials, parts, and units composed with some parts, and ID number and the present status are written in it. Status is rewritten according to becoming a unit from materials. The IC tag attached on a unit transmits ID number, current position, and status through network system whenever it passes through the gate provided in the inside of the factory, the construction site, in the transfer route between them, and the entrance of a warehouse, etc.

On the other hand, as for the production planning side, progress management of the production project is performed by the scheduling system after a master schedule is drawn up. The scheduling system can show the position and status in which each part / unit should exist. By comparing with real-time information on each part / unit transmitted through network system to the

information on the master schedule, a gap between the master schedule and an actual state is detectable. According to the quantity of a gap, re-scheduling is performed when the system judges it is needed.

3. SYSTEM ARCHITECTURE

The architecture of parts and packets unified manufacturing system is explained on this section. Figure 2 shows the system architecture in the case of parts processing and assembly processing in a factory. The network system built by the conventional intelligent manufacturing system has combined production facilities, such as production cells and stations. Meanwhile, in the proposed system, the information that each part have in IC tag can be exchanged with network system through the gate provided in each production facilities. For example, at the gate provided in the outlet of a processing facility, the status of parts is rewritten according to the contents of processing.

If the memory capacity of IC tag will become large in the future, it is also possible to compose a network system only with IC tags attached to the parts by storing processing processes and work information in IC tag, and exchanging information about them with production facilities. However, since the present IC tag has not satisfactory memory capacity, the proposed system hybridized the network system which combines production facilities, and parts and packets unified system. Process and work information are transmitted to production facilities from the scheduling and CAM systems through the network. The part ID in the ID tag is checked and after processing process,
CAM system.
Then, the link with IC tag and the network system is described. Two methods can be considered for linking with IC tags and the network system in the field activities; those are shipped and conveyed from a factory, stored in a warehouse, stored in a construction site, performed assembly, and installed as a final position in a building. One is the method of using hand scanner type IC tag reader / writer. By this device, the position, time, and status information of each part can be read / written. The other method is providing gates, which can operate information on IC tags, in required places in the field. By this method, since the data on a IC tag can be automatically read / written when passing through the gate, it is especially useful in a warehouse and a construction site.

Here, the realization of the component driven type construction system by linking IC tags with the network system is discussed. For example, the component assembly process by a robot as shown in Figure 3 is considered. The robot acquires information of a component from a operation server using ID number attached to the component, then operates the component, and sends ID number and the work result of the component it operate to the server. On the other hand, the operation server performs operation and management of components information, and sends the information about a component to a robot according to requested component ID number. [Umetani]

This method using parts and packets unified system can grasp the position of each component on real time. Therefore, parts and packets unified production system can be carried out using data in real time not only for production planning or scheduling but also for work planning such as planning conveyance route from materials place to assembly position including the sequence of the crane operation. This system can also cope with the case of producing by comparing with actual material management to master schedule.

4. APPLICATION TO DYNAMIC SCHEDULING

In the manufacturing system in a factory, the information of what part and when exists is important. On the other hand, in a construction production, the information of where a part exists is indispensable. For example, efforts for looking for parts in production site, or efforts for arranging parts when they are on the place where they must not exist, are often seen. Although the former function can be supported directly by the proposed system, the method of describing existence position of component corresponding to production schedule is needed in order to realize the latter function. Realization of this function is a future work.

Here, an application system of production process within a factory is explained as an example of the parts and packet unified production system. The components of the system are shown in Figure 4. This example has the following preconditions.

- This factory has following facilities; those are five machining cells, two AGVs (Automated Guided Vehicle), and a storage.
- Previously, the initial value of machining ability on each machining cell is set up as shown in Table 1. If the ability of machining cell changes during the production, proposed scheduling system calculates new value using the started and finished processing time data obtained from parts.
- The manufacturing process in this system is limited to machining operation processes.
- Part processing which consists of several jobs

![Figure 3. The component driven type construction system by link with IC tag and network system.](image1)

![Figure 4. The component of manufacturing system in a factory.](image2)
is prepared as a candidate for production example.

- The order of processing jobs is determined beforehand, and cannot be changed.
- Each part has processing geometrical form and volume as data, and machining time is calculated based on these information.
- Scheduling is performed according to the SPT (Shortest Processing Time First) rule which makes the shortest average processing time in the job shop.
- It is assumed that the conveyance capability of two AGV are equal, and it moves in the orbit with one way. Therefore, the distance between each cell is given to a meaning as shown in Table 2.
- Table 3 shows an example of the work data. According to this work data, each job is given with processing order. Moreover, the processible cell is beforehand decided according to the processing type.

<table>
<thead>
<tr>
<th>Processing form</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>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 1</td>
<td>20</td>
<td>30</td>
<td>12</td>
<td>30</td>
<td>30</td>
<td>20</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>Cell 2</td>
<td>25</td>
<td>24</td>
<td>16</td>
<td>24</td>
<td>15</td>
<td>24</td>
<td>30</td>
<td>22</td>
</tr>
<tr>
<td>Cell 3</td>
<td>20</td>
<td>30</td>
<td>16</td>
<td>32</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>Cell 4</td>
<td>30</td>
<td>30</td>
<td>16</td>
<td>30</td>
<td>10</td>
<td>30</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>Cell 5</td>
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<td>24</td>
<td>16</td>
<td>12</td>
<td>30</td>
<td>30</td>
<td>12</td>
</tr>
</tbody>
</table>

**Table 2. The distance between machining cell.**

<table>
<thead>
<tr>
<th></th>
<th>storage</th>
<th>Cell 1</th>
<th>Cell 2</th>
<th>Cell 3</th>
<th>Cell 4</th>
<th>Cell 5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5</td>
<td>10</td>
<td>15</td>
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<td>20</td>
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<tr>
<td>Cell 2</td>
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<td>25</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Cell 3</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>0</td>
<td>5</td>
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<td>Cell 4</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Cell 5</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Some virtual simulation was performed using the system. Here, the making re-scheduling corresponding to the ability fall of a machining cell is introduced as an example case. This system checks number of waiting parts work in machining process of each machining cell derived from position data of the part, and If the number of waiting part is rather than a setting number, this system performs re-scheduling. On re-scheduling

Using those data, the simulation model which performed machining process was constructed. The total image of a factory model is shown in Figure 5. In this model, each part has position and time data on IC tag. By receiving these data on real time, the system check the number of waiting part for machining process, and calculates the machining ability of each machining cell at any time. Then, when an actual state differs from a master schedule, re-scheduling is performed dynamically.

**Table 3. Work data of proposed system.**

<table>
<thead>
<tr>
<th>Parts ID</th>
<th>Job ID</th>
<th>Group ID</th>
<th>order from</th>
<th>Volume</th>
<th>Processible</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3, 5</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1, 2, 4, 5</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1, 2, 3, 4</td>
<td>0</td>
</tr>
<tr>
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<td>4</td>
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<td>2</td>
<td>5</td>
<td>2, 3, 4, 5</td>
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<td>3</td>
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<td>9</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>200</td>
<td>1, 2, 3, 4, 5</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>8</td>
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<tr>
<td>4</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>200</td>
<td>2, 3, 5</td>
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<tr>
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<td>1</td>
<td>2</td>
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<td>1</td>
<td>3</td>
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<tr>
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<td>1</td>
<td>4</td>
<td>5</td>
<td>200</td>
<td>1, 2, 4, 5</td>
</tr>
</tbody>
</table>

**Figure 5. The simulation model of the factory.**
process, the ability of the cell is re-calculated by using information on the processing start time and finish time from latest processed part.

The Gantt chart of the simulation is shown in Figure 6, and temporal change of the number of waiting parts work in process is shown in Figure 7. In each figure, (a) the master schedule, (b) the result when not dealing with the ability fall of a machining cell., and (c) the result of after dynamic scheduling are shown. As these results, the system worked effectively against changing state of production facility. This shows that the parts and packet unified production system has feasibility of dynamic re-scheduling according to environment.

5. CONCLUSIONS

The following conclusions can be drawn.

- It is thought that parts and packets unified system is available in construction production.
- The concept and the architecture of parts and packets unified system were proposed.
- A case study about the scheduling system in a factory was shown and the feasibility of parts and packets unified system was discussed.

- The issues for using parts and packets unified system more effectively to construction production was considered.

From these conclusions, it is possible enough to apply this architecture to the field of construction production. By combining these different fields by the same management architecture, it is believed that distributed decision making between enterprise, which treats wide range domain, is also realizable.
6. ACKNOWLEDGEMENT

This research is supported in part by “Innovative and Intelligent Parts-Oriented Construction (IF-7 II)” Project (IMS 96009).

7. REFERENCES


Virtual Video-Sensitive Interface Used in Robotic Control

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ABSTRACT: The paper presents a video-sensitive virtual interface used in technological process controlling. The control panels are substituted by this graphical system, with all advantages that can be focused from there. In robotic control are involved many controlling instruments and whole this set can be implemented with some virtual controls such as below description. Into complete application of robotic control system is necessary a hardware structure coupled on the PC’s parallel or serial port which assures the bi-directional information transfer. This

KEYWORDS: Robotics, Interface, Programming Language, Image, Virtual, Microcontroller, Sensitive.

1. INTRODUCTION

An interface is defined as an adaptive system in concordance with the controlled technical process requests and the controlling subsystem. The classical interfaces most often are the hardware structures. Some structures involve specific disadvantages like as:

- high cost (production, maintenance, transport etc.);
- low reliability and physical wear in time;
- high environment factors sensibility;
- high mechanic and electric inertia;
- low up-grade capability.

All this disadvantages can be eliminate by total change between classical interfaces and virtual interfaces.
A virtual interface is an example of primordial software structure, where the hardware is an insignificant part.
This paper is focused to show, like as man-machine interfacing solution, an unusual virtual interface type: the video sensitive interface.
The graphical interfaces are involved where the man-machine interface must be optimized [3].

The video sensitive interfaces become from the graphical interface class. One same interface use a combination between a real image which is captured in live mode by video camera (a person’s image) and other graphical image which is synthesized by the computational system (some buttons for example). The interaction between the two images is coordinating on-line by the involved person. Thus, in virtual mode, is possible to press a key like as simple gesture in the air.

2. SOFTWARE ENVIRONMENT

The software environment, which was selected, is C++Builder. The choice was be made for speculate the advantages involved by this software environment. Thus, the C++Builder is a visual programming environment and has on base the C++ programming language that is considered in actual moment the best programming language for the lower applications. This aspect assures to the system the developing quality. Other reason for C++Builder choice is the easeful management by computer ports (serial and parallel ports). Under C++Builder exist implements specific function’s libraries in ports controlling, which are optimized and tested by a lot of users in various applications. When is necessary to optimize the system from resources implemented (is possible to wish a software system which adapting to more simplify hardware system) can be using the C standard programming language.
3. THE VIRTUAL INTERFACE

Video interface implementation into the live dynamics is easeful performing in C++Builder [2]. The \texttt{CapSetVideoArea(VideoArea)} sets the builder component into is made the capture. The label which will receipts the state information from the driver, is processed by \texttt{CapSetInfoLabel(VideoLabel)} function.

The opening of the setting capture source window (the video-camera) is performed by \texttt{CapDlgVSource()} function. The setting format for capture perform is made by \texttt{CapDlgVFormat()} function. In present application was opted for the 320x240 TrueColor.

The image processing procedure is based on the contour analyze algorithm. For that in defined first the background like the image layer which not supports position’s variation. The dots from the frame which accepts the motionless condition on all time of prescribed analyze (was been considered a 2 seconds time interval), will belong to background class. The rest from layer is considered moving object. In this mode, the person will be identifying periodically with a 2 seconds rate. The contour analyze will be made on the dynamic image (on the person’s image). The video-sensitive points are considered the graphical buttons (figure 1). For this is first performed a positioning analyze. The coordinates thus determinate will be stored into the witness vector. Next step consists in launch one the periodically analyze routine for the possible coordinates superposing between the dynamic object area (the person) and the video-sensitive areas (graphical buttons). This one state like as identified will conducts to a specific decision in concordance with the button was been pressed.

4. THE COMPLETE INTERFACING SYSTEM

Like a hardware subsystem can be used any electronic interface board coupled to one from the computer’s ports or just a system with microcontroller [Mahalu]. Much more is need a video camera coupled to a PC system. In this application was been used a Logitech kind camera.

The whole structure of the video-sensitive virtual interface system is presented in figure 2.

![Image with sensitive areas](image.png)

\textit{Figure 1. Image with sensitive areas}

The block notations from figure 2 have the signification:

- video camera VC;
- computer PC;
- interface board IB;
- technological process TP.

The interface board used is DAQ801 type with the follow features:

- 40 ks/s sampling rate;
- 12 bits resolution on the analogue input;
- 8 analogue inputs with simple reference or differentials;
- 2 D/A channels on 12 bits;
- 3 timer/counter on 16 bits;
- 32 digital I/O channels;
- auto-calibration and auto-axing on zero;
- possibility to scanning on the channel with various gain factors;
- FIFO date buffer on 2 kB;
- programmable gain on 1, 10, 100, 1000;
- interrupt management possibilities;
- firm’s soft drivers;

![The control system structure](image.png)

\textit{Figure 2. The control system structure}
Technical specifications:

**Analogue inputs:**
- Input impedance – 1 MΩ
- Voltage protection – up to +20 V
- Conversion time – with auto-axing on zero: 25.6 µs, without auto-axing on zero: 15.2 µs
- FIFO data buffer – 2K (1024 samples)
- Scanning list – 8 inputs
- Error on zero – to zero adjusting
- Gain error – to zero adjusting
- Integral linearity error - ±1 LSB
- Noise – in voltage for 1.7 mV

**Analogue outputs:**
- Channels – 2
- Domain - 0÷±5 V, ±5 V
- Resolution – 12 bit
- Integral linearity error - ±1 LSB
- Output impedance – 0.5 Ω
- Output current – 2 mA

5. THE RADIO-INTERFACING SYSTEM

A good solution of interfacing performs is to use a radio transmitter-receiver structure coupled by the PC’ port. A same structure can be realized using Bluetooth technology. However, is possible imagining own communication structure on the high frequency. One same structure is following presented.

6. THE CODING BLOCK

The coding block can be realized in various architectures, in respect with the request imposes to the data sets.

One data coding solution consists in generating by a set the various frequency signals with different commands signification. The easiest way to release a same system is to use a divider clock signal block. Thus, one frequency by one time is emitting and no more another. This structure is shown in the figure 3.

In the signals multiplexing goal can be used a CLC structure. With this, one single signal is transferred through an AND gate at one time. All the rest of the signals will be inhibits because all other AND gates are disabled. One example of same structure is shown in figure 4.

Another data coding solution using the wide pulse modulation train. This method is able to coding the binary information. Thus, for the “1” logical value is generated a pulse with the $d_1$ wide, while for the “0” logical value is generated a pulse with the $d_2$ wide.

The main advantage of these coding techniques consists in the superior technical performances and in the simplicity. The coding block will be, in this case, useful to designing and implementing and without problem to put to point. The decoding block from the receiver system wills uses by same advantages. The major disadvantage is the law data transfer speed. Indeed, the data transfer speed is in related with the mean between $d_1$ and $d_2$ widths. This widths can’t be decreased too much because appear the risk to penetrate in the false pulses domain. Same pulses appear from technical causes both to the electromagnetic field level and the electronic circuits of the system implemented level. After the theoretical analysis and the practical tests by some the witness structures we ascertained that the minimal width for the pulses $d_1$ and/or $d_2$ most to be up than 100 ms. Is
understanding what for the data transfer speed is the bounded by the unusually low values. The result is that some solutions can be adapted only when the data succeeding speed requests involved by the controlled system are not big. This is the case that involves great time constants, characteristic for the systems with delays. One codifying block like that above described, using the monostable structures, is shown in the figure 5.

Figure 5. The coding structure

7. DESCRIPTION OF THE WORKING SYSTEM

The SR register is with the parallel input and serial output. When is applied a pulse on the STEP input in the DATA-OUT output appears the next binary value that was loaded in the register. After N pulses in the STEP input applied, with N the SR’s register dimension, all the stored bits in SR register are obtained in the serial output. The first STEP pulse that is provided by the tact formatter-generator, immediately after that is obtained in the DATA-OUT output of the last bit stored in the SR register, will triggering the loading parallel process. This process will be completed with the extraction in the serial output of the register of the first bit from the new set by the bits was been stored (we refer to most significant bit). The current bit, which is obtained in the DATA-OUT output, is applied by the SW switch command input. This switching one by outputs denoted by l and 2 respectively in “0” logical. Since the outputs are connected each by the monostable input, after the OR logical gate will obtain one pulse with d1 or d2 about what the bit from DATA-OUT was “1” or “0” logical value. This pulse commands the transmitter circuit denoted by E, which will emit a frequency modulation signal with the d1 or d2 width. Same pulse provided by the OR’s gate will triggering the M monostable which will commands the shifting to right with one step of the information contained into SR register, with a τ delay.

Another possible solution is that used the UM 3758-120A specialized integrated circuit (see figure 6). This chip provides a width modulated pulses train, in relation with the electric states of those twelve inputs, from A0 to A11. These physically inputs can be coupled to +12V, to ground or just lets to air. In that mode is possible to generate 531441 distinctly codes. In figure 2 is shown an example of using that circuit for generating two codes. This structure uses A11 and A12 inputs. When the S1 and S2 push-button are pressed is obtained in Tx output the corresponding pulses train for the codes. The C1 and R1 components impose the working frequency for the synchronization oscillator from the coding block circuit.

8. COUPLER WITH THE PARALLEL PORT

The coupling with the parallel port uses an 8-bit buffer that performed so safe separations between the PC port and the adjacent electronics structure. For this buffer can be used specialized logical circuits or just some simple buffers with high impedance outputs. One same block is presented in figure 5. The write mode output signals of this buffer are coupled to the shift register with the parallel inputs and the serial output, in the second case of codify example. For that is possible to be used the 4021 circuit for example [Franklin]. Anyway, in accompany all these will be necessary to be involved a logical control block that processing the state signals from the parallel port. This block will performed too some specific signals designed to the rest of the electronic board interface.
9. RECEIVER STRUCTURE

In receiver block, the command signal is decoding and only one by 8 output signal lines will be active in 1 logical state, if is working with the CLC codifying block (see figure 5). For to decode a command coded like above is necessary to use a binary counter circuit. This circuit count up just a specified time (called validation time) and function of the frequency command signal the number which result after ending of the counting is more big or more small [Franklin]. All the outputs of the counter circuit constitute an 8-bit bus and this is coupled in sequence to a binary decode circuit. In this mode only one output by the binary decode circuit is activated one time. In figure 7 it shown the described structure.

For remark, whole that structure is used when the coding block generates like signals different frequencies. When width coded pulses are generated, still can be used this structure if a decoder width-time block is used between the receptor block and the counter. One that decoder block is possible to be building with the structures which involves monostable circuits.

When the system contains the UM 3758-120A chip, the decoding block is more simplified because the chip above named can be used like decoder too. In this case the input signal is applied into Rx circuit’s input and the output consists in the Tx signal of the chip. The Tx output is a zero logical state while on the transmitter board is pushed the command button. Just is possible to be used more one chips, with the inputs parallel coupled and the distinctly outputs dedicated to the specifics channels. However, in one this case are more necessary some auxiliary blocks, such as logical gates, flip-flop circuits and operational amplifiers.

10. INTERFACING WITH THE PC SYSTEM

When is wished the performing an interfacing between the radio-system board and the PC, will be necessary to create some protocol software procedures. Those procedures must be leading the data control signals transfer on the electronic board. The language which implements the communication protocol from the PC system computer can be a high level language such as the C or the FORTH language.

When is used a microcontroller structure, the system is done independently by the PC. This feature can be exploited in many cases that involve the mobility and low cost requests.

A specifically microcontroller type structure is presented in figure 8. Remark that the system is able to achieving the analogue signals and/or the numeric signals too. The system has the own mini-keyboard and the LCD devices.
11. CONCLUSIONS

The developing of software structures and using these more often in the technological processes request implement of the virtual interfaces. These devices become with a set of advantages comparing with the classical interface man-machine, and can conduct to a high quality and economic factors, which are involved into consumption society. The news technologies brings a series of information processing and transfer mechanisms with the specific behavior (like as the Web and Internet technology). The society must be prepared to receiving these technologies and involve them in more knowledge areas.

12. REFERENCES


Figure 8. The microcontroller type structure
Performance Evaluation of Construction Business Process Reengineering

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ABSTRACT: This study endeavors to focus on developing an evaluation method for comparative analysis of process performance before and after reengineering. Business Process Reengineering (BPR) is a relatively recent concept that has stemmed from management and computer science roots. Process performance evaluations are crucial to managers in identifying the benefit of new process after reengineering. Currently, BPR lacks an effective method of measuring performance. The primary objective of this study is to define a structured process to evaluate the process performance based on the Process Value (PV). The PV, consisting of two major factors, namely process time and customer satisfaction, is developed to evaluate the procedural performance. Process time is an index used to measure the process efficiency, while customer satisfaction is applied for evaluating process effectiveness. Concept derived from the Queueing Theory is used to analyze the time performance of BPR, and Target Attainability Matrix is applied to quantify the customer satisfaction. Dividing process effectiveness with process efficiency, the PV is obtained to assess the reengineering results. The evaluation method has been successfully implemented to real operations in construction industry. It is used as a basis from which business managers can clearly understand the process performance difference before and after reengineering. In addition, the results provide a good reference for those interested in adopting BPR in the industry.

KEYWORDS: Business Process Reengineering, Performance Evaluation, Queueing Theory, Process Value

1. INTRODUCTION

Ever since Hammer elevated BPR in 1990s[Hammer & Champy 1993], most of the articles discussing BPR are only about statements of its steps, design methods, procedures, and prospects after application. They hardly touch upon BPR’s performance evaluation methods and standards, leaving businesses unable to figure out the differences before, during and after the application of BPR. A set of proper mechanism of BPR performance evaluation can help businesses understand the differences between before and after reengineering, employ efficient resources on right processing, and build a continuous improvement sequence to deal with any business competition.

Therefore, the primary purpose of this study is to use the idea of “BPR, Queueing Theory, and Process Value (PV)” to develop a “Construction Management Process Performance Evaluation (CMPPE)” model shown in Fig. 1. Using CMPPE, construction company can systematically identify and define the major procedural categories of construction management. Further aims are as follows: Concept derived from the Queueing Theory is used to analyze the time performance of BPR; Target Attainability Matrix [Cheng, 2003] is applied to quantify the customer satisfaction; and Dividing process effectiveness with process efficiency, the PV is obtained to assess the reengineering results. Finally, precise calculation on the performance value difference after reengineering can assure that the success of reengineering may prevent construction companies from applying new processing without a thorough performance evaluation. This study can serve as a basis from which to execute process reengineering and process performance evaluation.

![Figure 1. Structure of “Construction Management Process Performance Evaluation (CMPPE)” model](chart)

<table>
<thead>
<tr>
<th>CMPR</th>
<th>Business process reengineering</th>
<th>Process representation</th>
<th>Process evaluation</th>
<th>Organization adjustment</th>
<th>Process redesign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reengineering performance evaluation</td>
<td>Process time estimate</td>
<td>Customer satisfaction evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reengineering performance confirm</td>
<td>Process value calculation</td>
<td>Value added rate calculation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


2. BUSINESS PROCESS REENGINEERING

Using Construction Company A as an example, this study is aimed on construction management process performance evaluation that includes Bidding/Contract, Cost estimate/Construction Plan and Procurement/Subcontracting process. Within the Procurement/Subcontracting process, Based on four steps of work in the BPR analysis procedure. The study suggests implementation of Information Technology (IT) and the Internet and Intranet techniques to develop a management information system. Also the study creates case committee with content experience engineers and staff to execute each project for curtail processing time and reduce cross department activity. Furthermore, the study creates decision-making center to support the General Manager for authorizes commitment, recourse distribution and to negotiate with deferent department, reducing obstacle in process operation. Finally, the development of the IDEF0 diagram for Procurement/Subcontracting process is shown in Fig. 2.

![Figure 2. IDEF0 Diagram of Procurement/Subcontracting Process](image)

3. REASSURING PROCESS REENGINEERING PERFORMANCE EVALUATION FACTORS

By interview with top executive and employees, this research defines performance evaluation factors as follows,

- **Efficiency of process reengineering**: difference of operation time length before and after process reengineering
- **Effectiveness of process reengineering**: difference of customer satisfaction before and after process reengineering

The research uses both ‘time’ and ‘customer satisfaction’ as indexes of process reengineering performance evaluation, whose framework and steps of evaluation are to be discussed below.

4. PROCESS REENGINEERING TIME FACTOR PERFORMANCE EVALUATION

The entire process, to a business, is like a gigantic queueing system. The followings are steps for process reengineering time factor performance evaluation.

**Step 1 Collecting information**

Investigate “The interval time between two bidding”, “The interval time between two award of contract” and “The interval time between two subcontracting”.

Take into account of every activity’s operation time and human resource needed in the process, then calculating every activity’s operation time per person of former process, define as “Service rate in activity”. Then survey and calculating “Service rate in activity” of each new process.

**Step 2 Information analysis**

This step is used to check the above information in the goodness-of-fit to insure the information is available to applying in queueing theory model, and to calculate expected value and variance of collected information, see Table 1 and 2.

**Step 3 Selecting queueing theory model**

Based on the result of the statistical test, the research has found that each arrival rate of bidding and service rate in activities does not show any possible distribution. With arrival rate of GI/G/1, queueing theory model’s arrival rate and service rate distribution can be of random of distribution, thus the research adopts GI/G/1 queueing theory model. The arrival rate and service rate of GI/G/1 model can be regarded as independent identical distribution and general distribution.

**Step 4 Establish queueing theory model**

The queueing theory model adopted by this research is a mathematic one emphasized by [Buzacott 1993]. The mathematic model has two major parts, First is the overall operational time(including waiting) in each activity (the summation of both time that project pending for implementation and being implemented) as shown in equation (1). The accumulation of each operational time thus lead to average overall processing time. Second is the operation departure rate (shown as squared coefficient of variation) shown in equation (2). Because operation
departure rate is often the arrival rate of the next activity, squared coefficient of variation in interarrival stages is need to be calculated.

\[ E[T] = \frac{\rho(2-\rho)C_a^2 + \rho^2C_s^2}{2\lambda(1-\rho)} + E[S] \] \hspace{1cm} (1)

\[ C_s^2 \geq (1-\rho)^2 + \rho^2C_s^2 \] \hspace{1cm} (2)

where \( E[T] \): Expected value of overall processing time in a activity per project; \( \rho \): (Expected value of processing time in a activity per project)/ (Expected value of interval time between two project); \( C_a^2 \): Squared coefficient of variance of interval time between two project (arrival rate; equal to previous activity’s departure rate ); \( C_s^2 \): Squared coefficient of variance of each operational time in a operation; \( \lambda \): 1 / (Expected value of interval time between two project); \( E[S] \): Expected value of processing time in a activity per project; \( C_d^2 \): Squared coefficient of variance of interval time between two project (departure rate).

**Step 5 Calculate overall processing time of both new and old process.**

Coding the queueing theory model program then input data of both new and old processes into the program, and calculate the overall processing time of each process. Procurement/Subcontracting process is taken as an example in the research to explain the following steps.

a. Establish operational process model based on represented process.

b. Input “Expected value and Variance value of the interval working hours between two award of contract” as shown in table 1 and “Expected value and Variance value of Service rate in activity” into program.

c. Output average time of each process: the program calculated the overall processing time in first activity by Eq.1 and departure rate of first activity(Squared coefficient of variance of interval time between two project) by Eq.2. Assume the departure rate of first activity is equal to next activity’s arrival rate. The program can calculate the overall processing time of next activity by Eq.1. By this procedure, the overall processing time of each activity in the process can be estimated.

The overall processing time of both new and old processes can be known by cumulating all activities’ overall processing time in the process.

**Step 6 Time performance evaluation before and after reengineering.**

Make a comparison in processing time between before and after reengineering. The shrinkage of overall processing time of the new process is obvious shown by Table 3.

**5. PERFORMANCE EVALUATION OF PROCESS REENGINEERING WITH CUSTOMERS SATISFACTION FACTOR**

Using the concept of Quality Function Deployment (QFD) method, this study transforms company policy and customer concerns into targets of process. This study is applying the method of “Target Attainability Matrix” in examining the attainability of target as an important source for measuring the effectiveness of process. The main steps of the evaluation process are described as follows.

**Step 1 Definition of the Operational Strategy and Policy of Company**

A company’s operation can be viewed as a serial composition of processes. Each process has targets to achieve. In this framework, it is essential to combine company policy with targets of each process in order to accomplish company policy. Before analyzing process, a company’s operation policy must first be defined. Inclusion of policy demands when setting process targets is also essential to the realization of a company’s operation policy and its customer needs.

**Step 2 Identification of the Internal and External Customers of the Process**

In the process operation, the output of the previous process is the input for the next. This means that the follow-up process will check the result of the preceding process. Based on this condition, the followings are the definitions of internal and external customers. Internal customers are those who actually participate in the process. External customer are the consumers who accept the final products of the process. The objective of this step is to identify the executor of each operation from the process diagram. The executor is the internal customer of the previous operation. Taking the example of procurement/subcontracting process, the internal and external customers of each process are identified and listed in the 2nd and 3rd columns of Table 4.

**Step 3 Surveying of Customers’ Requirements of Process**

Customer’s requirements have to be considered when setting process targets. Based on
the internal and external customers identified above, the demands of each customer are established and shown in the 4th column of Table 4. Expert’s interviews are used to collect customer’s requirements in the case of company A for the procurement/subcontracting process.

**Step 4 Determination of Process Targets**

The process must satisfy customer’s demands. To satiate customer’s demands, the process must have the capability to assign human resource and other related resources to accomplish the necessary tasks. Hence, this step treats customer’s demands as input information to determine the targets of process. The identification of process targets are described as follows:

a. Determination of the process targets according to customer demand. Process Targets Deployment (PTD) method developed in this study is used to transform the customer demands into process target. Taking the example of procurement/subcontracting process, the targets of the process as shown on the top of Table 4, are determined based on the PTD analysis.

b. Analysis of the relative importance of process targets. The relative importance of process targets is identified using Relative Importance Weight Evaluation Matrix (as shown in Table 4). In the matrix, customer’s demands are listed vertically in the left-hand side and process targets are listed at the top. Based on the relationship between the two, the corresponding number rij (rij: 1, 3, 5) is determined. The higher the value of rij, the more the target elicits customer’s demands. Then, considering the emphasis customers place on each demand, represent it as pj (pj: 1~5 points) and fill it in on the right-hand side of the matrix. The degree of emphasis is assessed by questionnaires and interviews. Finally, use equation (3) to calculate the score of relative importance (Wi) of each process target:

$$W_i = \frac{1}{\sum_{j=1}^{m} r_{ij} \times p_{j}}$$

where $$W_i$$: relative importance weight for process target i; m: the number of customer’s demands; n: the number of process targets; i: the ith item of process targets; j: the jth item of customer’s demands; rij: the corresponding rating between the ith process target and the jth customer demand, rij =1, 3, 5; pj: the emphasis degree of the jth customer demand; pj =1~5.

The score of process target ($$W_i$$) represents the degree of demand satisfaction that the process target delivers to the customer - the higher the score, the higher the satisfaction. Using the case of procurement/subcontracting process as an example, this study conducts interviews with senior managers to complete the Relative Importance Weight Evaluation Matrix for the company. The score of relative importance ($$W_i$$) of each process target is calculated as shown in Table 4.

**Step 5 Analysis of Process Target Achievement**

A quantitative method is used to calculate the achievement of each process target that the operational functions complete. Table 5, the Process Target Achievement Matrix (PTAM), illustrates this concept. Taking the case of after reengineering “Procurement/Subcontracting “ process as an example, the operation items in process diagram are placed on the left of the table and the process targets and scores of relative importance weight ($$W_i$$) are listed at the top of the table. Based on each process target, the attainability of each operation for each process target $$A_{ik}$$ ($$A_{ik}; 0~10/10$$) is evaluated by the senior managers. After completing the $$A_{ik}$$ evaluation, the Operation Target Attainability, $$O_{Ai}$$ ($$O_{Ai}; 0~W_i$$), obtained from the process activities can then be calculated. The Total Process Attainability (TA) of the targets and the degree of Contribution ($$C_k$$) endowed by each operation are also identified. The equations for calculating $$O_{Ai}$$, TA and $$C_k$$ are demonstrated as follows:

$$O_{Ai} = \sum_{i=1}^{n} W_i \times A_{ik}$$

$$TA = \sum_{i=1}^{n} O_{Ai}$$

$$C_k = \sum_{i=1}^{n} W_i \times A_{ik}$$

where: g: number of process operations; n: number of process targets; $$O_{Ai}$$: the attainability of ith process target achieved by the process operations; Aik: operation k’s attainability of the ith process target; TA: total attainability of process to the targets, TA=0~100; Ck: contribution of operation k.

$$O_{Ai}$$, TA, and $$C_k$$ can be used as indices for process evaluation. $$O_{Ai}$$ represents the process attainability of a certain process target - the higher the number the more probable the attainability. TA represents the process’ total attainability - the higher the value, the more suitable the operational function related to the process targets. Ck represents the contribution of a certain operation to all process targets - the higher the number, the
greater the contribution, which also means the function is more likely to satisfy customer demand.

**Step 7: Use Customer Satisfaction Comparison Before and After Reengineering**

Using the total attainability of process to the targets (TA) to evaluate the customer satisfaction. The TA of the process before and after reengineering are shown in Table 6

### 6. REENGINEERING PERFORMANCE CONFIRM

Performance is evaluated by “Process Value”[4], which is customer satisfaction achieved with time as unit, as shown in equation (7). Time unit is used to evaluate the speed to achieve customer satisfaction, as business seeks for more efficient way to reach expected goal after reengineering. Therefore, the sooner a goal is reached, the more value a process is added.

According to an investigation in 1993 and 1994, conducted by Gateway Management Consultant Company surveying CEOs, 90% of the recipients believe that when value added rate is over 25%, such performance can be seen as a breakthrough. This research also uses the “Value added rate” as a standard for evaluation value added rate of the process, Table 7 shows the application of equation (8) on processes before and after reengineering. Increase rate of three operational process after reengineering are over 25%; therefore, the performance of BPR in construction company A can be considered as a breakthrough.

**Processing value**

\[
PV = \frac{\text{Customer Demand}}{\text{Operation Time}} = \frac{\text{Process Total Attainability(TA)}}{\text{Overall Processing Time of Process}}
\]  

\
\text{Value Added Rate} = \frac{\text{PV After reengineering} - \text{PV Before reengineering}}{\text{PV Before reengineering}}
\]

**7. CONCLUSION**

This research can be concluded as follows:

a. Queueing theory is used to evaluate performance of time factor. With statistical calculation, one can explain differences before and after process time for objective analysis.

b. This research uses Process Target Attainability Matrix to analyze performance of customer satisfaction factors, regarding company’s expectations and customer’s needs as process elements, quantifying the attainability of each operation for each process target and identifying the Total Process Attainability (TF), which provide for the reengineering team to examine customer satisfactions of the new process.

c. The concept of process value can be used specifically to evaluate time efficiency and customer satisfaction achievement. It also serves to evaluate efficiency and effectiveness as reference for further research.

d. This research employs process time factor and customer satisfaction factor as performance evaluation on management process reengineering. It can also be applied to other management processes in construction companies for further research, such as the engineering operational process, the financial and accounting process, as well as the management operational process.

e. The established reengineering performance evaluation model of the research is to evaluate reengineering performance of management process in construction companies. It can also be used in future construction engineering life-cycle teams, such as architecture, consulting companies, professional construction management team to implement the process reengineering performance evaluation model.

### 8. REFERENCES


Table 1. Expected value and variance of Construction company A project arrival interarrival working hours.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Interarrival working hours from previous project</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Parking Lot</td>
<td>0</td>
</tr>
<tr>
<td>B Parking Lot</td>
<td>161</td>
</tr>
<tr>
<td>C Plant</td>
<td>94.5</td>
</tr>
<tr>
<td>D Building</td>
<td>546</td>
</tr>
<tr>
<td>E Building</td>
<td>780.5</td>
</tr>
<tr>
<td>F Building</td>
<td>322</td>
</tr>
<tr>
<td>G Building</td>
<td>791</td>
</tr>
<tr>
<td>H Building</td>
<td>507.5</td>
</tr>
<tr>
<td>Expected value (hours)</td>
<td>457.5</td>
</tr>
</tbody>
</table>

Table 2: “Service rate in activity” for Procurement/Subcontracting process (unit: hr/person)

<table>
<thead>
<tr>
<th>Name of Activities</th>
<th>Expected value</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect/Name List</td>
<td>1.63</td>
<td>0.34</td>
</tr>
<tr>
<td>Fill purchase form</td>
<td>220.76</td>
<td>1449.08</td>
</tr>
<tr>
<td>Apply for permission</td>
<td>100.75</td>
<td>353.07</td>
</tr>
<tr>
<td>Search Subcontractors</td>
<td>124.13</td>
<td>171.84</td>
</tr>
<tr>
<td>Collect/Name List</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Evaluate Subcontractors</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Request Quotation</td>
<td>45.75</td>
<td>119.36</td>
</tr>
<tr>
<td>Quotation negotiation</td>
<td>25.25</td>
<td>119.36</td>
</tr>
</tbody>
</table>

Table 3. Average overall operational time of process

<table>
<thead>
<tr>
<th>Process</th>
<th>Processing time (hours)</th>
<th>Old process TA</th>
<th>New process TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bidding/Contract</td>
<td>332.13</td>
<td>214.10</td>
<td></td>
</tr>
<tr>
<td>Cost estimate/Constr. Plan</td>
<td>724.45</td>
<td>201.38</td>
<td></td>
</tr>
<tr>
<td>Procurement/Subcontracting</td>
<td>71.74</td>
<td>33.65</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Relative Importance Weight Matrix for Procurement/Subcontracting Process

<table>
<thead>
<tr>
<th>Name of Activities</th>
<th>1.63</th>
<th>0.34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect/Name List</td>
<td>5.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Fill purchase form</td>
<td>5.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Apply for permission</td>
<td>5.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Search Subcontractors</td>
<td>5.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Collect/Name List</td>
<td>5.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Evaluate Subcontractors</td>
<td>5.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Request Quotation</td>
<td>12.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Quotation negotiation</td>
<td>12.3</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Table 5. Process Target Achievement Matrix for Procurement/Subcontracting Process

<table>
<thead>
<tr>
<th>Operation node</th>
<th>Name of Operation</th>
<th>Target components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Planning</td>
</tr>
<tr>
<td>Wt</td>
<td>12.3</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Table 6 TA of the process before and after reengineering

<table>
<thead>
<tr>
<th>Process</th>
<th>TA before BPR</th>
<th>TA after BPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bidding/Contract</td>
<td>62.1</td>
<td>89.3</td>
</tr>
<tr>
<td>Cost estimate/Constr. Plan</td>
<td>63.9</td>
<td>87.6</td>
</tr>
<tr>
<td>Procurement/Subcontracting</td>
<td>57.2</td>
<td>94.1</td>
</tr>
</tbody>
</table>

Table 7 PV of the process before and after reengineering

<table>
<thead>
<tr>
<th>Process</th>
<th>PV before BPR</th>
<th>PV after BPR</th>
<th>Value Added Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bidding/Contract</td>
<td>1</td>
<td>2.66</td>
<td>1.66</td>
</tr>
<tr>
<td>Cost estimate/Constr. Plan</td>
<td>1</td>
<td>4.27</td>
<td>3.27</td>
</tr>
<tr>
<td>Procurement/Subcontracting</td>
<td>1</td>
<td>2.55</td>
<td>1.55</td>
</tr>
</tbody>
</table>

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Automation of the design process

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ABSTRACT: Over the last 40 years ever more sophisticated computer hardware and commensurate developments in software have enabled much design to be computerised. More recently systems integration has allowed software to automatically pass data from package to package. This has effectively automated elements of the design process.

As with all developments there have been advantages and disadvantages. Automation has brought great efficiency gains and has removed many of the tedious aspects of design, but at what price? Generally designers resist the notion of automatic design and prefer to talk about efficiency of processes and the computer doing the “number-crunching”, leaving the designer “free to think”. However, despite the reluctance to acknowledge the phenomenon, [at least partial] automation of the design process has arrived. The reason why designers don't like the notion of automatic design is that automation implies loss of control and all designers should be (and are) fully responsible for all aspects of the process however efficient/automated it becomes. Whatever the semantics, there are major issues surrounding process automation and this paper explores the pros and cons in detail.

The benefits of design automation to the industry, and society at large, are considerable. Design is now faster and more accurate, and the whole process has been significantly enhanced by the available technology. However, it can be argued that the more automated the design process becomes, the more the designer loses the intrinsic feel for an appropriate solution. There are at least two documented significant structural collapses that have been, at least in part, attributed to computerised design. Lessons from both these failures are discussed in the paper. There are significant implications for the education and training of technical designers and at a more fundamental level, their basic skills-set. It is the fundamental requirement for an understanding of appropriate solutions that provides the link between automated design and the education and training of designers.

The paper does not argue that there are inherent deficiencies in computerised design but that there are differences between computerised and manual design than need be recognised, understood and managed. The effects of computerisation is so profound that the high-level numerical skills of engineering designers are now largely redundant but there is an even greater need for a deep understanding of behaviour and a "feel" for appropriate solutions. The paper concludes that the education and training of designers will have to change to reflect the new demands of the computerised design environment.

KEYWORDS: automation, computerised design, de-skilling, education, IT, process integration, training, skills.

1. INTRODUCTION

This paper investigates the effect of automation of construction design processes using the computer. Traditional automation concentrates on physical processes using machines and more recently robots, but design processes use intellectual rather than physical skills and these have been far harder to automate until the invention of the digital computer. As much engineering design comprises of mathematical modelling, and the computer is highly efficient at executing mathematical computation, it is clear that there is now scope for significant efficiency gains and/or automation.

For the purposes of this paper automation is taken to mean the computerisation of any design process that was previously executed manually, especially when separate operations are integrated into a single seamless process. Engineering design professionals are uncomfortable about the notion of automatic design, although efficiency of the process has become an established goal. It is the notion of a
machine automatically processing design information, without manual intervention, that seems to cause most consternation. Early software tools concentrated on specific aspects of design, and although they produced dramatic efficiency gains, this was not seen as "automatic" design. The current phase of engineering design software development has two facets that have changed this. The first is the ability of previously discrete packages to pass information automatically between each other. The second is the development and growing use of central 3D models. On their own, these developments are significant, together they are encouraging the total integration of all design disciplines (and construction and maintenance), which in turn facilitates automation.

The issues discussed in this paper apply to all technical design, but the author's experience in this area is based on structural engineering.

2. THE INFLUENCE OF COMPUTERS

Computers execute calculations at the touch of a button and much of construction design revolves around mathematical modelling and Computer Aided Draughting (CAD) which makes design processes an ideal candidate for automation.

Software is now so advanced that it effectively holds much of the detailed engineering knowledge (although critically not judgement). This can lead to the false assumption that the computer holds engineering expertise. The operator no longer needs to understand engineering processes or computation to obtain a solution.

The relative ease of producing calculations also encourages complexity, either in situations where a more straightforward design would suffice, or where the computational capability enables us to design more advanced system. In both cases this complexity may mask, or even encourage, error.

It is becoming increasingly difficult for younger engineers to develop the intuitive “feel” for technical design solutions and behaviour that their predecessors developed while producing manual calculations. It is this expertise that guides designers, and alerts them to inappropriate solutions.

There is also evidence to suggest that in some cases the power of the software is encouraging those with inadequate training or knowledge to engage in analysis and design, and in others that over-reliance is being placed in computer generated output. A combination of these factors can make error more likely and its detection more difficult. This risk needs to be recognised and managed.

3. DESIGN PROCESS AUTOMATION

Construction design can be broken down into various functions, most of which are ideally suited to computerisation. Technical design usually starts with a conceptual phase where real-world problems are analysed and idealised. This is a high-level skill, based on experience and although some software tools can assist, such as those based on artificial intelligence, this phase is not well suited to computerisation. When the real-world problem is broken down into discreet elements that can be modelled: analysis, design, drawing, detailing, scheduling and even planning, can be computerised. Once these processes are in an electronic form, partial automation has been achieved. When the software passes the output from one phase to another, full automation has arrived.

Although not strictly automation, another factor that is aiding the computerisation and integration of construction design is the development of full 3D building models. Additionally the recent innovation of centrally held and managed models, often utilising extranets or construction portals, will inevitably encourage electronic integration of design processes (and probably the organisational integration of traditionally separate design functions), that in turn will encourage further automation.

3.1 The benefit

Computerisation brings substantial benefits in the form of savings in skilled labour, faster design, error reduction and the ability to enhance design to a level not possible before the computer. The often quoted benefit of computers providing "more time to think" is however naive, where the need for efficiency will override any altruistic benefit. Any necessary "thinking" will be done irrespective of efficiency levels - any unnecessary thinking will still be unnecessary, however efficient design becomes!
The effect of efficiency gains must not be underestimated. Computations of great complexity, that would have taken hours to execute by hand, can now be completed in seconds. As software integrates analysis, design, drafting and scheduling, output suitable for manufacture can be created by one operator, from a single set of initial data. This is a potentially dramatic benefit that parallels productivity gains from automating physical processes. As complex calculations are performed by highly educated (and thus well paid), personnel, the potential cost savings are high. As a direct consequence of this automation, the skills balance of designers will change, with a reduced emphasis on mathematical skills and a greater need for conceptual abilities and knowledge of the operation, and critically, the limitations of software packages.

Apart from the obvious economic benefit of efficiency, speed of computation has made it possible to perform multiple iterations of complex designs allowing optimisation of solutions that were simply not feasible in the past. The rapid exploration of various design options will lead to enhanced product performance (as well as a more economically honed solution). Also, computer modelling of complex problems has led to more imaginative and creative structures (eg large stadia and aesthetically pleasing bridges), and safer buildings (eg modelling of the spread of fire, and the prediction of crowd behaviour).

Computers also have a significant role to play in error reduction. One of the traditional sources of design error was within manual computation. Proven software will virtually eliminate this as a problem. Data entry errors will be reduced by software integration, so automation via computerisation should provide substantial benefits in terms of reduction of this type of error.

### 3.2 The cost of the benefit.

As with the automation of physical processes, the benefits can only be achieved by the investment of capital. In this case it necessitates investment in hardware, software, communications systems and critically, technical support. This changes the balance between variable and fixed capital costs, increasing the reliance on investment and equipment, and requires access to capital. In turn this increases susceptibility to changing work volumes that are notorious within the built environment sector. In effect, capital expenditure allows variable costs to be saved but with increased financial risk [Gardner].

Rather ironically this benefit is ephemeral to the firm making the capital investment, as any cost-benefit eventually passes to society via more competitive pricing (but the risks associated with capital structures are permanent).

### 3.3 The problems associated with automation

In addition to the revised capital structure and the increased level of technical complexity, automation changes the process to such an extent that the risk of error alters significantly.

The use of computers in engineering design has become widespread, but the computer is only a tool. It could therefore be argued that computers should not alter the risk of error. However the evidence suggests that computer-assisted design does fundamentally affect the design process and can increase or decrease the risk of error depending on the circumstances. The potential for increased risk is illustrated below with two examples of catastrophic collapses, which have been attributed to computer error.

The problems associated with computerised design, come from the potential for unanticipated or unrecognised consequences as the design gets ever more automated and/or complex. As individual packages get linked together and data is automatically transferred between them, the risk increases as an error gets perpetuated, and is less easy to detect.

Errors have always occurred, some of which have led to catastrophic failure. Also some errors that would have led to catastrophic events have been avoided by utilising computer-assisted design (ie errors that would have occurred in manual design have been avoided). It is also unlikely that the same type of error would occur within computer and manual design, reinforcing the argument that computer-assisted engineering (CAE) has changed the risk. Error will continue, what has changed is the type and cause of this error. This necessitates different mechanisms for error detection, and the management of risk.
### 3.3 Computer assisted error

There are thankfully few examples where the computer has had a significant hand in catastrophic error. However there are two well-known structural collapses that are attributed, at least in part, to computer-assisted design, which together dramatically illustrate the issue.

#### 3.4.1 Hartford Stadium, Connecticut, USA

The Civic Centre in Hartford Connecticut, USA consisted of a 2.2 acre roof supported on only four columns. In 1978 when loaded with snow (but fortunately empty of spectators), it collapsed [Carper]. The complex roof was designed with considerable computer assistance and would have been virtually impossible to design manually.

The collapse was attributed to two factors: an eccentric joint was assumed to have no eccentricity, and a strut was assumed to be braced when in fact it was not. The strut that initiated the failure had a capacity of 9% of that assumed in the design. The actual working deflection was twice that estimated by the computer analysis. Despite a heavy snow load, the actual imposed loads at the time of collapse were well within the design limits [Levy and Salvadori].

It is reported that the structure exhibited signs of distress during construction (lack of fit of fabricated components) and in its subsequent operation (excessive deflection), but these warnings signs were ignored based on a false confidence in the computer-assisted design.

#### 3.4.2 Sleipner Offshore Platform

Sleipner was an offshore oil structure constructed in Norway. In 1991 it suffered a catastrophic collapse. The computer analysis was complex, using finite element analysis. It is reported that an error in the generation of the finite element mesh gave a poor representation of the shear forces at a critical joint, which resulted in a 45% underestimate of the shear force. The joint was also poorly detailed, exacerbating the problem. The combination of these two factors led to its failure and the subsequent loss of the whole structure [Foeroyvik].

### 3.5 Lessons from Hartford and Sleipner

Both structures were highly complex and relied on the computer for analysis. In the case of the Hartford Stadium, it could be argued that the availability of the computer had encouraged a more complex design, which exacerbated the problem. A simpler structure would have been easier to check with manual calculations. The construction of the Sleipner platform probably could not have been made significantly simpler and is a good example of the benefits of the computer's power being used to understand more sophisticated structures via complex analysis, but also illustrates the difficulty in checking this type of complex analysis. The problem here seems to be that the full implications of the design's complexity and the software’s limitations had not been fully appreciated.

Both structures were represented by models that were not sufficiently representative of the actual structure to give reliable results. Interestingly, despite the magnitude of these errors, in both cases the collapse was attributed to a combination of factors, rather than a single error.

### 3.6 Other errors

There are other less dramatic documented problems resulting from error and there must be many other errors (of a lesser magnitude) that have gone undetected and/or unreported. However, the literature does identify some significant cases that range from software and hardware errors, to seemingly obvious errors that appear to have initially gone unnoticed by engineers [Puri] [Krakty].

### 4. SAFER COMPUTING

This paper has presented two fairly dramatic well-documented structural collapses that are, at least in part, directly contributable to computers, and there are many more examples of error. This however this does not mean the computer is the villain of the piece, for two reasons. Firstly, the computer is programmed and operated by people, and however powerful, it is only another tool in the control of the designers. Secondly the computer has allowed us to design and construct far more complex buildings than were possible in the past.
The evidence suggests that most computer-generated errors come from deficiencies in the modelling process, or a lack of understanding of the limitations of the software, rather than the actual computation or errors in the software itself. This gives us the first clue to developing a strategy to address the issues.

The problem comes down to CAE having a tendency to divorce the computation from a deep human understanding of structural behaviour and a “feel” for the likely solution. This is exacerbated by the fact that CAE encourages structural complexity (some justified by the project and some not).

Many organisations have recognised this and have published guidelines for the safer use of computers in engineering calculations. These usually recommend a systematic approach to computer analysis that breaks the process into a numbers of stages, each with its own verification and validation procedures, and the management of the process by qualified and experienced personnel [ISE] [NAFEMS].

Ultimately it is the industry’s responsibility to ensure it uses computers in a safe and appropriate way. The future must lie in education and training, and controls that ensure only those with appropriate knowledge, training and experience have responsibility for design output.

5. EDUCATION AND TRAINING

Every error must eventually be attributed to people (rather that the computer), but the issue is far more complex than simply distributing blame. Some computer error is attributed to software faults but analysis of known errors suggests that it is far more common for errors to occur as a result of correct computation of an inappropriate model. This establishes a direct link between the education and experience of the computer operator and the likelihood of an error occurring.

There is evidence of a "black box" syndrome developing in relation to computer analysis, whereby false confidence is generated in the output just because it came from a computer. This appears to be the case with the Hartford Stadium failure, where the structure exhibited signs of distress that were discounted because "the design was executed by computer". This creates a paradoxical situation whereby it is relatively easy to generate an answer for a complex problem by computer (and difficult to do this manually), but the complexity of the analysis and/or the problem itself, requires greater experience to recognise problems with the computer output.

Computerisation which embeds design information in the program also allows software to be operated by less experienced staff.

It is widely accepted that engineers gradually develop "a feel" for appropriate solutions by grinding through manual calculations. In the computer age the necessity for manual calculations has all but disappeared, making it more difficult for the engineer to develop this feel. The dilemma is that computer design increases the importance of an intrinsic understanding behaviour but that this feel for an appropriate solution is now more difficult to obtain.

This problem is exacerbated when computers are used to design complex structures that are virtually outside the capabilities of manual computation. It is of course one of the great benefits of computers that they are enabling us to design ever more complex and imaginative structures, but a consequence of this situation is that errors are more likely to go undetected. Both of the structures cited in this paper are complex and almost certainly would have been built differently had computers not been available to assist with analysis.

This problem gets even more complex if it is concluded that the skill-set required for traditional manual design (highly mathematical) is different from that required for computerised design (conceptual, developing appropriate models and appreciating the likely solutions to a problem). Whereas engineers have traditionally required highly developed mathematical skills, needing "left brain" skills, it is argued by some, that developing an inherent feel for appropriate engineering solutions, and the ability to develop appropriate models (suitable for computer analysis), is a far more imaginative skill needing "right brain" attributes [Brohn]. If this argument is correct it will have radical implications for the selection and training of future design engineers, as more will need to be drawn from different sections of the population (it is generally thought that left and right brain attributes are a matter of birth rather than education and training).
Computerisation will also affect the design of technical courses. Most traditional engineering courses have high levels of mathematics, the need for which has been radically reduced. The emphasis will need to shift to modelling and interpretation of results, rather than the historical emphasis on mathematics and analysis.

The implications of automation are indeed dramatic!

6. CONCLUSIONS

Despite the obvious difference between design and physical processes, there are great parallels in relation to automation. Considerable economic and performance benefits can be realised by investing in technology that automates design. The benefits are quantitative in terms of faster and more efficient design, saving the higher cost of traditional manual design and qualitative in terms of design enhancement. Automation also increases financial risk, changes the required skills and alters the chance and type of possible error.

We are entering a phase where most engineering processes are at least partly computer-assisted and the integration of design processes is leading to further automation. It’s critically important that the implications of these changes are fully understood.

The cases of catastrophic failure described in this paper dramatically support the contention that computer assisted design can lead to significant error, which highlights a problem which needs to be recognised and managed. However errors will always occur and no error can ultimately be blamed on the computer. All error eventually links back to people.

Computer assisted design reduces the necessity for engineers to have high-level mathematical skills and the evidence suggests that the emphasis should now be on conceptual design, modelling and interpreting the output of computer programs, rather than having the skill to actually perform the computation (which computers do so effectively). It is also far more difficult to develop a feel for behaviour and likely solutions as a result of computer-executed design and the more complex buildings that computer design has made possible. It is argued by some authors that this fundamentally changes the required skill-set of designers and that these issues need to be fully reflected in the education and training of engineers. A combination of these effects will change the future manpower requirements for engineers.

It is the industry’s responsibility to ensure that the undoubted benefits available from computers are achieved without an unacceptable change in the associated risk.

7. REFERENCES


Industrialized Building Systems: Reproduction before Automation and Robotics

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ABSTRACT: Industrialization is the aggregation of a large market to divide into infinitesimal fractions the investment in a technology capable of simplifying the production of complex goods and therefore reducing the costs. Simplification is the goal. Whenever the first four degrees of Industrialization, Prefabrication / Mechanization / Automation / Robotics, transfer the tasks from craftsmen to machines, they merely replace people with machines and duplicate the traditional processes (it is normal: new technologies always go by the traditional patterns first). Things are different with the fifth degree, Reproduction. Reproduction implies innovative processes capable of short-cutting the long sequential operations of craftsmanship nature – i.e. capable of categorically simplifying the production, as notably illustrated by the analogy of Printing / the Printed-Circuit / the Printed Plumbing Core. Using performance criteria, in order to avoid a captive image from the past, one can select promising options through the “Technology Matrix” (where processes interact with materials) and thereafter generate building system aiming at Reproduction.


1. INDUSTRIALIZATION

Even if we live in the post-industrial era, where any product done in a craftsmanship fashion is bound to be luxury, there is still a lot of craftsmanship in the building industry today and the old saying is still true: if a car was produced the way buildings are delivered, very few people would be able to own one; if an electronic calculator was produced the way buildings are delivered, it would cost a fortune.

The advantages of industrialization and post-industrialization are based on quantity: to justify with an important market the investment in a technology capable in return of simplifying the production of complex goods. That is the very nature of industrialization: a large quantity of units will divide the investment into small (eventually infinitesimal) fractions, thereby reducing the production costs of a single unit down to marginal amounts and making (if the economy is transferred to the pricing) the product available to a large audience.

For instance, if you build a chair for yourself, you will buy some wood, glue, paint and, using hand tools, you will probably devote some 10 to 15 hours to do it. If you foresee a large market of 50,000 chairs, then a more sophisticated process will have to be considered, perhaps plastic injection: the mould itself costs a lot, over 50,000$, but it will produce plastic chairs at the rate of one per five minutes: that is one dollar per chair plus material; plus the fee to the manufacturer that has invested in the injection machine hosting your mould.

Therefore, the critical investment in a more productive process, although costly at the outset, is generating a benefit progressing with the number of units produced, once the break-even point is reached. Of course, the injected plastic chair presents a completely different design, visually and aesthetically; but, if the Performance Criteria are governing and if they are clearly spelled out, it can be as solid, as comfortable and as beautiful in its own way.

2. DEGREES OF INDUSTRIALIZATION

Five degrees of industrialization are usually recognized. The first four are Prefabrication, Mechanization, Automation and Robotics: they are usually duplicating the traditional processes, merely transferring the tasks from the craftsman to a very expensive machine.
Whereas the fifth, which we will call “Reproduction”, implies research and development of innovative processes truly capable of simplifying the production (Richard 2002).

2.1 Prefabrication

Pre-fabrication start with “pre” which means “before” and/or “elsewhere”. In the building industry, it generally implies building in a factory components or full modules very similar to the ones done on a traditional construction site, and in most cases using the same processes and the same materials.

Still, for the following reasons, prefabrication can very often bring the construction costs down, as much as 15% in some instances:
- Rationalization of the tasks along a production line;
- Specialized tooling and handling equipment;
- Semi-skilled labour;
- Climatic protection;
- Better quality control.
- Bulk purchasing of raw material due to the single delivery point.

2.2 Mechanization

Relying on mechanized tooling to ease the work of the labour (pneumatic harmer, power tools, etc…). Usually the case whenever there is prefabrication.

2.3 Automation

The tooling is taking over the tasks performed by labour; the foreman is still around, although the engineer and the programmer are the critical people involved. A study about Swedish wood-frame panels assembled by automation indicates an economy up to 27% compared with traditional construction methods.

2.4 Robotics

The same tooling is performing by itself diversified multiple tasks.

2.5 Reproduction

Reproduction is the introduction of an innovative technology capable of simplifying the production of complex goods, of short-cutting long sequential operations. Therefore achieving more substantial economies than mechanizing, automating or robotizing around the traditional construction methods, as it is the case with the automation of wood-frame panels production for instance.

Of course, Reproduction is not necessarily available as a downright option: it is often present together with some of the other degrees industrialization.

3. THE “PRINTING” ANALOGICAL CHAIN

The analogical chain triggered by the Printing process is quite prolific and can illustrate the full meaning of Reproduction: Printing does replace in two movements the long sequential activities of the script, the Printed Circuit produce in two operations all the connections between the components of an electronic device, the Integrated Circuit replace the components with an additional operation, and the Printed Plumbing Core is providing in two operations all the conduits required for the kitchen & bathroom.

3.1 Printing

Instead of hiring a staff of copyists to rewrite “n” copies of the Bible, Gutenberg carved a large amount of wood types. He invested a lot of time in doing that, more time than to rewrite one, two, three even four copies of the Bible. But when the types were available, Gutenberg assembled them to produce a full page, inked them and then made contact with “n” sheets of papers to produce “n” copies of the page. Reassembling the types to produce the other pages, he was thereafter able to produce “n” copies of the Bible a lot faster than the copyists.

Gutenberg has therefore justified quantitatively a process capable of simplifying the production of a complex product. The rotary press that came later went even further by replacing the on-off operations by a continuous production; a knife separates the pages at the end.

3.2 The Printed Circuit

If the electronics industry had replaced by machines the labour welding components to wires in the old wired circuit, they would have moved to Mechanization, Automation or even Robotics. But
a “new Gutenberg” had the idea of replacing the time consuming multiple hand-made welding by a simple and almost instant operation: silk-screening a negative of the circuit paths on a plate, and generating a positive conducting network by electro-deposition (see figure 1). The “Printed Circuit” has a completely different configuration than the wired circuit, either man-made or even automated, but it meets the same performance criteria much better (less space, high precision and more solidity). And the product can be modified just by changing the pattern of the silk-screening (Richard 1972).

3.4 The Printed Plumbing Core

Let us move from the printed circuit to residential plumbing; as plumbing is also a network connecting components. Traditionally, the pipes are cut to pieces, attached to couplings / gaskets and connected on the site between themselves and to the fixtures one after another. Years ago, some manufacturers did offer a "Prefabricated Plumbing Core", but the market did not respond.

Heinz Wager (Wager) and others (Biondo & Rognoni) came with a bright proposals, directly related to Reproduction: an innovative “Printed Plumbing Core” formed by two complementary (“left hand – right hand”) pre-moulded sheets (vacuum formed plastic or deep-drawn aluminium) where each sheet has the conducts embossed as half circles (see figure 2).

An adhesive applied with a roller covers only the flat parts: when the two sheets are bonded face-to-face, the flat parts become unified and the half circles become open conduits.

3.3 The Integrated Circuit

The Integrated Circuit went one grand step further: printing the components themselves on the circuit. And this explains the multiple low cost electronic devices available on the market today.

Figure 1. Wired circuit and Printed Circuits

Figure 2. The Printed Plumbing Core
4. THE TECHNOLOGY MATRIX

Based on those analogies, we can define as the key to industrialization the development of an innovative process capable of simplifying the answer to a complex set of requirements (Richard 2002) i.e. reaching the Reproduction level. Once the user’s needs are spelled out and the sub-systems identified, the performance criteria are the facilitators when the designer is searching for a new technology: by aiming at the performance rather than the form, the criteria will permit a more open and creative selection of technologies (see figure 3).

That approach means, quite appropriately, a new image of the product, closely related to the process as it was the case with the injected plastic chair and the printed circuit. The results can lead to a production economy up to 50%.

Like the painter who can select form the basic colours spread on the palette, the designer can start with a Matrix of technologies, where processes interact with materials (see figure 4).

Figure 3. Selection of technologies

Figure 4. A Matrix of technologies

On such a Matrix, one can locate, for instance:

- the two interactions that led to the PRINTED CIRCUIT: coating (silk-screening) ink (misc.) over lead (other metals) electrodeposited on a plate;
- the two interactions that led to the PLUMBING CORE: deep-drawing an aluminium sheet (or vacuum-forming a resin sheet) and covering with adhesive the flat parts.

Using the Matrix in a similar manner, with the performance criteria as a guideline, a creative designer can combine various processes and materials to generate different technologies for different components or sub-systems of the building industry. The following components are already-on-the-market examples of the type of results that approach can generate:

- HOLLOW CORE SLAB: Extrusion of concrete along a line of pre-stressed cables; rather than building (and dismantling) formwork, installing the reinforcing, delivering and pouring the concrete on the site; the cheapest way to produce a structural slab.
- MULTIFUNCTIONAL LIGHTWEIGHT CONCRETE PANELS: Casting or
pressing or moulding a monolithic panel integrating thermal & acoustical insulation, air & vapour barrier, structural or bracing capacity, cladding and texture as well as the jointing geometry; then spraying a coating to achieve waterproofing; rather than putting up a stud wall with insulating blankets, air and vapour barrier membranes, exterior sheeting and cladding as well as interior finish. Similar to the Misawa Homes’ Pre-cast Autoclave Lightweight Concrete (“PALC”).

- SINGLE SHELL BATHROOM & WATER-CLOSET BASE: incorporating all the components (bath/wash-basin/shower/even toilet bowl) and facilitating the maintenance (round corners and no tile joints) in composite, through deep-drawing, covering or even centrifugation; rather than laying & grouting tiles on a waterproof backing. Or producing the same shell in metal through electro-deposition; similar to Buckminster Fuller’s bathroom proposal.

5. THE PRINTED SERVICE-CORE

By doing to the Printed Plumbing Wall what the Integrated Circuit did to the Printed Circuit i.e. “printing the components themselves”, we can mould or cast in two complementary parts, using lightweight concrete, the box that groups the kitchen/W.C./laundry/mechanical-electrical shaft/stairs/etc. and integrating at the factory all the plumbing and most of the wiring; rather than installing the elements one by one at the site or prefabricating the plumbing core. We could prospectively produce the full “serving” unit of the building in a single module that can be called the “Printed Service Core” (see figure 5).

6. THE PRINTED LOAD-BEARINGSERVICE-CORE

The next step is to make it load-bearing as it could, out of its full 3D module features, support totally or partially the floor of the open spaces around, like the vertical circulation core of an office building. The “Printed Load-Bearing Service Core” will simplify the production of the “serving” area(s) and therefore simplify the production of the complex part of the building = reducing the construction cost.

The “Printed Load-Bearing Service Core” can reduce the costs due to its Reproduction level manufacturing process, but it also simplifies the site assembly: being a 3D module, it is self
supporting and could be figured to structurally support the slabs generating the “served” area (living room, dining room, bedrooms, etc.), the exterior wall panels and the interior partitions. The job-site requirements are then limited to simple connections.

But, as it is the case with most process based innovations, the image of the product is not conform to the traditional patterns. The “Printed Load-Bearing Service Core” adds a geographical discipline to the planning process, which is not new with office building but very rare in residential building.

A new architectural language can be generated through that discipline if the architects can accept to bypass the freedom of locating the services wherever their concept dictate or the usual logic of grouping the services at the centre of the building.

7. CONCLUSION

There is more to do than was done and there is no limit to the possibilities of the Technology matrix or “palette”: innovation is more promising in the Matrix than in the Mechanization / Automation / Robotics of our traditional craftsmanship methods. Therefore the emerging technologies should be aiming at the simplification of production rather than replacing the human hands with machines: Reproduction rather than Automation or Robotics, and of course Mass Customization rather than Mass Production.

8. REFERENCES


Automated Handling of Construction Components
Based on Parts and Packets Unification

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ABSTRACT: This paper proposes a method of pose (position and orientation) fitting of construction components in a construction site for automated handling based on the relation between components (parts) and their information (packets). Robots can acquire the required information of the component via the environment-attached storages, such as RFID devices. When an ID reader identifies an ID device, it should take some pose in its communication range. This fact may bring the idea of estimating the pose of a component that carries the device. In this idea, only single device identification cannot fix the pose of the component. We define the conditions of the ID reader and ID devices for the pose fitting, and propose a fitting method with at least two different identifications where two devices are not attached to the same plane or parallel planes of the component. Several examples of pose fitting show the feasibility of our idea.

KEYWORDS: Automated Handling, Pose Fitting, ID devices, Radio Frequency Identification

1. INTRODUCTION

The recent advancement of information and communication technologies has brought feasibility of efficient construction automation. Robot arms or automatic machines have been developed in order to apply to a construction task [1][2]. These robot arms need information acquisition systems to achieve tasks in construction sites. We have proposed the construction automation system using based on the relation between construction components in the construction site (parts) and their information (packets) [3]. Robots or workers obtain task information for achieving tasks via components in the workspace. And the parts are strongly related to the parts information. Therefore the robot can obtain the required data for achieving tasks easily [4][5][6][7]. The acquired information via the environment-attached storages improves the sensing ability of the robot.

A robot requires current pose information of component when it achieves automated handling. Since the current pose of component will be changed in the process of construction, it is not easy to store it in the packet or the database. The pose should be measured or estimated in any way to achieve handling.

In this paper, we propose a method of pose (position and orientation) fitting of a construction component using multiple ID devices [5][8]. The basic idea is to estimate a component pose in the reference coordinate frame based on the movement of the ID reader and a series of ID device poses in the component frame. When the ID reader accesses a device, its pose information can be obtained in the component frame. However, a single device cannot define the component pose uniquely. If the robot obtains a set of device poses attached on the component, the component pose can be defined perfectly in the reference frame. These devices should be attached carefully on the component sides.

In the followings, we will define the geometrical relation between an ID device and the reader. Then, we will show that the pose of the component can be estimated using the pose data of at least two ID devices attached.

2. SYSTEM CONFIGURATION BASED ON PARTS AND PACKETS UNIFICATION

We have proposed the idea of “parts and packets unification”, where we use an ID device attached to each component to define the relation of construction components with their information. The actual component data, including component attributes, relation among components, and so on, are stored in the database. The database of components and task plan are managed comprehensively and consistently. Robots or workers can obtain task information via construction components (i.e. parts) at a construction site. And the
parts are strongly related to the accompanied component data (i.e. packets).

Figure 1 shows a relation between construction robots, components, and their information. A robot can acquire required information for the task and about the component via ID attached and it can accomplish the task by operating the component. First, the robot acquires an ID from the actual ID device attached to the component. The robot sends the acquired ID and the task results to the operation server while achieving the task. The operation server creates required information for achieving the task using the ID and sends the required information to the robot. Then, the operation server updates the component data according to the task results. There are several methods to acquire an ID in this system, for example, RFID device, bar code. The communication between the robots and the server may be a private network or the Internet.

When an RFID device is applied, a geometrical relation of device and its reader can be defined in the access. This idea leads to the pose fitting of component.

3. POSE FITTING USING ID READER

3.1. Acquisition of ID attached to the component using ID reader

Figure 2 shows a method of obtaining an ID using the ID reader. An ID device is attached on the surface of a construction component. The ID reader is mounted on the robot hand, and the position and orientation of the ID reader is estimated based on the kinematics parameters of the robot.

As shown in Fig. 2, the robot can detect the ID, when the device comes within the communication area of the ID reader. There are several problems in using ID devices:

- It is difficult to obtain the pose of the component that the ID device is attached.
- The robot cannot obtain the distance between the ID reader and the component by detecting the ID device.

3.2. Fitting of component pose

A component pose will be fit by reading multiple ID devices attached to the component. We propose a method of fitting a component pose in the reference frame. The idea is to use the movement data of the reader and the device pose in the component frame read by the ID reader. In this method, the robot can make the plan of the ID reader to read the other ID devices for pose fitting of the component from the obtained ID of the ID device attached to the component.

There are some assumptions in our fitting method. Several ID devices are attached to the surface of a component, and the poses of the ID devices in the component frame are registered in the operation server as component data in advance. When the ID reader detects a device, there is only one device within the communication area of the ID reader.

Figure 3 shows our proposed idea. First, the robot searches an ID device attached to the component by moving the reader. When the robot detects a first device and obtains its ID, the robot sends the ID and the robot pose to the operation server. The server searches the device pose data represented in its component frame. The server tries to find a near ID device on the component, and sends the coordinates of the next ID device to the robot for its motion planning. Then, the robot will search the next ID device.

When the robot obtains the next ID, the robot again sends the ID and the robot pose to the server. The server estimates the origin of the component frame with respect to the reference frame, that is, the pose of the component. Once the robot obtains
In the fitting process, the correct pose of the ID reader can be obtained, since it is calculated using the robot kinematics. A series of the device poses in the component frame can be obtained by matching the IDs and the component data in the operation server. Therefore the robot can estimate the pose of the component using an ID reader without any sensors.

4. POSE FITTING ALGORITHM

In this section, we discuss an algorithm of pose fitting of component using ID devices. First, we define the geometrical relation of the ID reader and ID device when the reader detects the device. Next, we show the pose of the component in the reference frame using the relation. Last, we discuss the property the fitting result because of the relation of the pose of ID devices used for the pose fitting of the component.

4.1. Model of ID reader

In order to fit a pose of the component by reading the attached ID devices, we define a model of ID reader. The properties of the reader are the followings.

- There is a communication area along the axis of the reader. It is shown as a dotted line in Fig.4. The actual communication area can be modeled by a 3-D volume.
- The reader can obtain an ID of the device if the device exists within the communication area and the device is directed to the reader surface.
- There is only one ID device within the communication area of the reader.

Figure 4 shows a relation of an ID reader and an ID device in the reference frame. $\Sigma^O$ indicates the reference frame, $\Sigma^R$ indicates the coordinate frame of the ID reader, $\Sigma^C$ indicates the coordinate frame of the component, and $\Sigma^D$ indicates the coordinate frame of the ID device. $d$ indicates a distance between the reader and the device, and $\alpha$ indicates a rotation angle about z-axis of the reader frame.

Generally, the distance cannot be obtained by just reading the device. We will define a geometrical relation model between a reader and a device based on the properties of the reader. To make the model easier, we assume some additional conditions that the device exists on the axis of the reader, and the orientation of the device is directed to the reader surface. Therefore we define the conditions that the reader detects the devices as follows:

1. The position where the reader can detect the device is on $z$-axis of the reader frame.
2. The distance that the reader can detect the device is initially unknown and $d>0$ is assumed.
3. The rotation angle $\alpha$ is initially unknown.
4. The direction of $z$-axis of the device frame is to the opposite direction of the $z$-axis of the reader frame.

From the condition (1) and (2), we can define the position of the device using the homogeneous transformation matrix of the ID reader with respect to the reference frame $^O{T_R}$ and the matrix of the ID device with respect to the reference frame $^O{T_D}$ as follows:

$$
^O{T_R} = \begin{bmatrix}
0 \\
0 \\
0 \\
1 \\
\end{bmatrix}, \quad ^O{T_D} = \begin{bmatrix}
0 \\
0 \\
0 \\
1 \\
\end{bmatrix}. 
$$

And from the condition (3) and (4), we obtain the relation of the orientation between the reader and the device using vector $a^R$ and $a^O$. $^O{R_D}$ is a rotation matrix of the reader with respect to the reference frame and vector $a^R$ is its third column. $^O{R_D}$ is a rotation matrix of the device with respect to the reference frame and vector $a^O$ is its third column. The relation is shown as follows:

$$
a^R = -a^O. 
$$
We can obtain the relation between the reader and the attached device for the pose fitting of the component.

### 4.2. Pose of attached device

We discuss the relation between the ID reader and the ID device attached to the component. \( p_{R,D1} \) represents the position of the reader with respect to the reference frame where the reader detects device D1. From Fig. 4, the position of D1 is described by using equation (1) as follows:

\[
O_{TR} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = O_{TC} \begin{bmatrix} x_{C,D1}^C \\ y_{C,D1}^C \\ z_{C,D1}^C \end{bmatrix}
\]  

(3)

where \( p^C_{D1} = [x_{C,D1}^C, y_{C,D1}^C, z_{C,D1}^C]^T \) is the position of D1 with respect to the component frame. And \( O_{TC} \) is the homogeneous transformation matrix of the component frame with respect to the reference frame.

The relation of the orientation between the reader and the device is expressed by the equation (2). The relation of the orientation between the reader and the attached device is described as follows:

\[
O_{R} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = O_{R}^{C} O_{R}^{C,D1} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = 0
\]  

(4)

where \( O_{R}^{C} \) is the orientation matrix of the component with respect to the reference frame, and \( O_{R}^{C,D1} \) is the orientation matrix the device with respect to the component frame. From the equation (4), we obtain

\[
[R_{O}^{R} O_{R}^{C} C R_{D1}] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = I_3
\]  

(5)

where \( I_3 \) is a unit matrix. Here we define the following matrix.

\[
[R_{O}^{R} O_{R}^{C} C R_{D1}] = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix}
\]

From equation (5), the element of the third column is \( \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}^T \). Since the matrix is orthogonal, it is described as follows.

\[
[R_{O}^{R} O_{R}^{C} C R_{D1}] = \begin{bmatrix} c_{11} & c_{12} & 0 \\ c_{21} & c_{22} & 0 \\ 0 & 0 & -1 \end{bmatrix}
\]  

(6)

By considering that \( \alpha \) is a rotation around z axis, the equation can be rewritten as follows.

\[
[R_{O}^{R} O_{R}^{C} C R_{D1}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} Ca & -Sa & 0 \\ Sa & Ca & 0 \\ 0 & 0 & 1 \end{bmatrix}
\]  

where \( Ca = \cos \alpha, Sa = \sin \alpha \), and \( R_{x,z} \) indicates the rotation of \( \pi \) about x-axis. Here \( \alpha \) is still arbitrary. Therefore we can obtain a rotation matrix of the component

\[
O_{R}^{C} = O_{R}^{R} R_{x,z} R_{z,z} R_{z,\alpha}^{D1} R_{C}^{C}
\]  

(8)

We will discuss the property of the component pose when the reader detects the attached device. The homogeneous transformation matrix of the component frame with respect to the reference frame \( O_{TC} \) is expressed using equation (8) as follows:

\[
O_{TC} = \begin{bmatrix} O_{R} R_{x,z} R_{z,\alpha}^{D1} R_{C}^{C} & p \\ 0 & 0 & 0 & 1 \end{bmatrix}
\]  

(9)

where \( p = [x,y,z]^T \) is the position of the component with respect to the reference frame. The position of the attached device is expressed using equation (3) as follows:

\[
O_{TC} \begin{bmatrix} x_{C,D1}^C \\ y_{C,D1}^C \\ z_{C,D1}^C \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}
\]  

(10)

Now, we define the position of the component with respect to the reader frame.

\[
p^C = \begin{bmatrix} x^C \\ y^C \\ z^C \end{bmatrix} = R_{O}^{R} (-p_{R,D1} + p)
\]  

(11)

The position of the attached device can be obtained using equation (10).

\[
\begin{bmatrix} x^R \\ y^R \\ z^R \end{bmatrix} = -R_{x,z} R_{z,\alpha}^{D1} R_{C}^{C} \begin{bmatrix} x_{C,D1}^C \\ y_{C,D1}^C \\ z_{C,D1}^C \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ d_{D1} \end{bmatrix}
\]  

(12)

Since \( R_{D1}^{C} \) is given, from equation (8), \( x^R \) and \( y^R \) are described by sine and cosine function with the same coefficients respectively. Therefore the origin of the component frame is on a circle in the x-y plane at given \( z^R \).

When the reader detects the attached device, the origin of the component frame with respect to the reference frame, that is, the position of the component is on the surface of a cylinder whose center is on the axis of the reader. The orientation of the component is not defined and has one degree of rotational freedom.
4.3. Fitting 3-D pose of the component using two ID devices

We will discuss a method of fitting 3-D pose of the component using two ID devices. We define that the reader position is \( \mathbf{p}_{R,D1} \) when the reader detects device D1, and that the rotation matrix of the reader is \( O^{R(D1)}_R \).

The pose relation between the reader and the component is obtained by detecting two attached devices D1 and D2. First, we consider the pose relation using one device pose by detecting D1. We define two homogeneous transformation matrices, the reader pose \( (O^{T(D1)}_R) \) and the component \( (O^{T(D1)}_C) \), with respect to the reference frame.

These matrices are shown as follows:

\[
O^{T(D1)}_R = \begin{bmatrix}
0 & R^{(D1)}_R & \mathbf{p}_{R,D1} \\
0 & 0 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

\[
O^{T(D1)}_C = \begin{bmatrix}
0 & R^{(D1)}_C & \mathbf{p} \\
0 & 0 & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

where \( O^{R(D1)}_C \) indicates a rotation matrix of the component using a rotation matrix of device D1 with respect to the component frame (see equation (8)). From equation (3), the position of the component can be obtained as follows:

\[
\mathbf{p} = \mathbf{p}_{R,D1} - O^{R(D1)}_C \mathbf{p}_{C,D1} + O^{R(D1)}_R \begin{bmatrix}
0 \\
0 \\
d_{D1}
\end{bmatrix}
\]

(14)

It is also described by using the pose of device D2.

\[
\mathbf{p} = \mathbf{p}_{R,D2} - O^{R(D2)}_C \mathbf{p}_{C,D2} + O^{R(D2)}_R \begin{bmatrix}
0 \\
0 \\
d_{D2}
\end{bmatrix}
\]

(15)

The orientation of the component, that is, the rotation matrix, is fixed while the reader detects two devices. From equation (14) and (15), we obtain

\[
\mathbf{p}_{R,D1} - \mathbf{p}_{R,D2} + O^{R}_C \left( (C_{D2} - C_{D1}) + O^{R(D1)}_R \begin{bmatrix}
0 \\
0 \\
d_{D1}
\end{bmatrix} - O^{R(D2)}_R \begin{bmatrix}
0 \\
0 \\
d_{D2}
\end{bmatrix} \right) = 0
\]

(16)

where the rotation matrix of the component with respect to the reference frame \( O^{R(C)}_C \) is

\[
O^{R(D1)}_C = O^{R(D2)}_C R_{z\alpha_{D1}} R_{z\alpha_{D2}}^T R^{(D1)}_C
\]

and \( \alpha_{D1} \) is the rotation angle of device D1 about the reader axis. From equation (16), we obtain three equations for \( \alpha_{D1}, d_{D1}, \) and \( d_{D2} \). By replacing \( \alpha_{D1}, d_{D1}, \) and \( d_{D2} \) by the solution of equation (16) in equation (14) and (17), we obtain the pose of the component. Figure 5 shows the relation of the reader and two attached. Equation (16) is expressed based on this relation. From Fig. 5, the pose of the component is obtained based on the relative position between two attached devices and the relative position between two reader positions with respect to the reference frame.

Now, we suppose that the vectors of the third column of matrix \( O^{R(D1)}_C \) and \( O^{R(D2)}_C \) are the same, that is, the reader detects two devices having the same direction. Since these devices are attached to the component, they should be on the parallel planes of the component. In this case, we define relative distance \( d = d_{D1} - d_{D2} \), then \( d \) is obtained by equation (16). But \( d_{D1} \) and \( d_{D2} \) cannot be determined directly. The rotation matrix of the component with respect to the reference frame can be obtained. Therefore another condition is required in order to define the pose of the component when two devices attached on the parallel planes of the component. For example, the component is on a known plane.

We have tried experiments of 2-D pose fitting when the component is fixed on a floor of the room using our method. The pose of the component is fitted by two device detections. Sometimes the pose fitting errors have been observed. It is considered that these errors are mainly due to the modeling error of the reader and that the error may be reduced by carefully selecting the attached points of the devices.
5. CONCLUSIONS

This paper proposed a method of pose fitting of construction component using multiple attached ID devices in order to achieve automated handling in construction. We introduced the geometrical relation model of a reader and a device to fit the pose of the component. We showed that the 3-D pose of component could be fitted using at least two ID devices attached to the component. The orientation of the component is fitted but the position of the component is not estimated if the reader detects multiple ID devices attached on the parallel planes of the component.

When the reader detects one ID device, the position of the component is on the cylinder whose center is on the reader axis. The orientation of the component is not defined and has one degree of rotational freedom. This result shows a pose of second ID device can be estimated based on the pose fitting of the first device. It is useful to plan a search motion of the reader in order to detect the second ID device.

There is a communication area along the axis of the reader. The communication area can be expressed by a 3-D volume. The reader axis is not always in the same direction of a device and this may cause the estimation error of the pose fitting. This estimation error has not been discussed in this paper and remains to be a future work.

This time we assumed a pose of a device with respect to the component frame. Then it is required to measure the pose of device when the ID device is registered to the database in the actual application. Since a device is attached to a component directly, a simplified model of the device is required.

In the future works, we will propose the modeling of ID device with the consideration of the communication area, the pose fitting of the component, the estimation of the modeling error, the automated handling of the real component, and so on.

6. ACKNOWLEDGMENT

This work has been carried out in the IMS international joint research program IF7-II. We would express our appreciation to Dr. Tomohito Takubo, Osaka University, for his suggestive discussions.

7. REFERENCES


ABSTRACT: Most past attempts to deal with the unique challenges facing mobile construction robots have involved tasks such as position finding, local mapping, and automatic calibration. It was found that the combination of numerous small errors, such as incorrect positioning of the robot’s carriage or inaccuracy in interpreting the environment, with minor inaccuracies in the robot’s arm movement, can result in errors of several millimeters. Thus, the robotic performance of high-precision or delicate tasks, such as in-situ tile setting or block laying, almost becomes a “mission impossible”, unless real-time sensing and correction is applied for each and every element as it is set in place.

This paper presents a concept that enables an indoor mobile construction robot to be positioned in the close vicinity of its temporary workstation, with an approximate accuracy of about 10 centimeters. The robot then calibrates itself to the immediate environment, which is relevant only to the current workstation. The movements made by the robot’s end-tool when bringing a building element (e.g. a tile) to its target position are directed in real-time by sensing the tool's immediate surroundings. The overall task cycle may start with a swift long-distance movement of the arm towards the target, followed by a series of fine, short-distance iterative “Sense-and-Act” cycles. This consistent interaction with the immediate environment renders unimportant many errors that may occur in the broader environment.

This general “Sense-and-Act” concept was applied and tested on one of the most challenging interior tasks for robots, namely accurate tile setting on walls. This task requires three-dimensional precision to the millimeter. A special device was developed for the delicate “Sense-and-Act” cycles of tile setting. The device consists of a CCD camera and several laser projectors, combined with sophisticated computer image processing. The device developed is introduced and discussed in the paper, along with a presentation of full-scale tile setting experiments.


1. INTRODUCTION

1.1 Related construction robots

Many studies conducted in the last two decades, sought a suitable way of introducing robotics into the field of construction.

Many research works suggested highly autonomous robotic systems for the performance of construction tasks, without fully investigating their implications. It is obvious that high levels of autonomy require the use of sophisticated sensory devices. Berlin (1994) described a robot designed for concrete surface processing, which receives the floor planning as an input, and after an automatic calculation of its moves, presents them to the operator for improvement before acting. Andres et al. (1994) suggested a masonry robot that pre-plans its tasks in detail. In spite of this, the robot introduced inaccuracies due to erroneous calibration, arm deformation, and so on. A complying end-tool was therefore suggested, which was designed to compensate for such inaccuracies. Chamberlain et al. (1994) conducted experiments with a masonry robot that relied on detailed planning but also required sensory devices for accurate interaction with its environment. The researchers noted the advantage of not needing to know the robot's absolute position. Pritschow et al. (1996) also dealt with a masonry robot designed to operate in an autonomous manner. This robot, however, could not assure the accuracy of every movement without the use of auxiliary devices and sensors.

Some researchers attempted to increase the autonomy level of robots by enabling them to
map their environments and independently navigate through them. The mapping and navigation methods should then be adapted to construction sites, which are characterized by inaccurate geometries, numerous obstacles, and so on. Such navigation methods are expected to be able to deal with these difficulties, and succeed in achieving accurate enough results. Forsberg et al. (1997) suggested a robot for plastering that uses a rotational laser beam to measure and map its surroundings (walls and openings). The mapping data should be translated into a working plan, which would be presented to the operator for improvements. The suggested system depends on accurate navigation methods, should bring the robot to within ±1 cm of its workstation, a feat that appears to be unattainable.

Beliveau et al. (1996) developed an orientation system for indoor automated guided vehicles (AGVs), using three laser transmitters accurately positioned on the floor at known points. Experiments with this system revealed that the deviation of the measured path from the desired path was ±10 cm.

Shohet and Rosenfeld (1997) examined the achievable accuracy of automatic mapping of indoor construction environments. It was found that under conditions of precise robot positioning (orientation and location errors of 0.2° and 3 cm, respectively), the achievable accuracy of environment mapping is 3-5 cm. This accuracy is sufficient for tasks that do not require touching the treated element (e.g. spraying); however, tasks that involve precise placing of elements (e.g. block laying and tiling), require a mapping accuracy of 2-3 mm, as well as the utilization of well-controlled end-tools. The study concluded that this level of accuracy cannot be achieved at construction sites.

1.2 Related robots in other fields

Real-time planning is commonly employed in robotic tasks that are required to contend with uncertainties and undefined environments, yet must be performed accurately.

Tillett et al. (1995) claimed that the use of accurate robots for agricultural tasks is unjustified, and that it would be more suitable to use less accurate robots that are guided by a vision system. This approach was implemented in a robotic system for packing tomatoes. A camera identified tomatoes on a tray and guided the end-tool in grabbing them one-by-one using a suction device.

Sevilla and Baylou (1991) characterized agricultural robotic work. Some of the characteristics described resemble those of robotized construction: Identifying various types of objects in natural environment conditions; interactivity between sensors and end-tools; working under undefined and sometimes hostile conditions; suiting the robot configuration to changing surface conditions, and so on. The authors noted that vision systems are best suited for the identification of a range of sizes, shapes, and colors. Yet, in order to simplify the vision analysis it was suggested to add and integrate other sensors as well. For example, an automatic milking system was constructed that recognizes udders by projecting a laser beam on them, the marks of which were detected by a camera. Different projection angles enabled the construction of a 3D representation of the udders (Figure 1).

Figure 1. Udder detection (Sevilla & Baylou, 1991).

Another example of real-time planning was a robot vehicle that identifies asparagus plants on a furrow by means of a camera and a light projector (figure 2).

Figure 2. Plants detection (Sevilla & Baylou, 1991).

Sevilla and Baylou clarified that a main problem in robotized agriculture is the difficulty in calibrating the system in relation to its environment. The common devices used for
environment detection are not accurate enough for the performance of such tasks; hence, the use of sensory devices for detecting the immediate environment of a treated element is required.

A different field in which real-time planning can be demonstrated is welding by robots. In such tasks, the robot identifies the seam to be welded and tracks the seam while welding it.

A well-known method for seam tracking utilizes a camera and a laser beam. In this method, a laser beam is projected on the seam and a CCD camera identifies the broken line, which is indicative of the location of the seam (Figure 3).

Figure 3. Seam detection using a laser and a camera (Haug and Pritschow, 1998).

1.3 Problem definition

Initially, robots were developed for the manufacturing industry and were intended to perform routine tasks in a very familiar environment, while fixed to the floor. Unlike such robots, those designated for work on construction sites must be mobile, maneuver in changing environments, and perform a different task at almost every step. Researchers and developers of autonomous robots for indoor construction tasks have attempted to solve the problem of adjusting the robot to its environment by developing automatic mapping and self-positioning methods. The robot then autonomously navigates from one workstation to another. Yet, it is clear that these methods are not likely to conform to the accuracy requirements of many construction tasks. In most cases, the robot must be accurately positioned at its workstation. Moreover, even when the correct positioning of the robot is assumed, accuracy of the robot’s arm, or even that of the environment’s interpretation, is not sufficiently reliable. The accuracy of the manipulator’s moves may differ in each cycle due to variations in the load at the arm’s end and in the arm configuration. Creating a more robust arm, one that would be less sensitive to the varied loads and trajectories, would lead to heavier and more expensive robotic systems with lower economic feasibility.

The drawbacks of the existing work methods are manifested most clearly when performing element-setting tasks, such as block laying and tile setting. In the latter case, it is essential to set each tile on the correct wall-plane, and to maintain the correct distance from other tiles set earlier as part of either the current workstation or previous workstations. Every visible error will adversely affect the outcome, or worse - could cause overlapping when trying to set one tile on top of another.

2. THE SUGGESTED CONCEPT

The concept presented herein suggests that the robot merely be positioned (or self-positioned) at its workstation with an approximate accuracy of several centimeters. After positioning is completed, the robot will be calibrated relative to its immediate environment (the environment relevant to the workstation), and according to the robot’s actual position, the system will plan (or re-plan) the appropriate manipulator moves. Moreover, the movement of the robot’s end-tool to its position will be directed in real-time by sensing the tool’s immediate surroundings. In other words, for each manipulator move used in the placing of an element, the system will ascertain the correct positioning of the element by performing several “Sense-and-Act” cycles. This consistent interaction with the immediate environment will eliminate many errors that may occur in a broader environment, such as location mistakes, mapping errors, manipulator deflection, and so on.

Three main steps are performed after stabilization of the robot at the workstation, as follows:

Rough calibration - After stabilizing the robot at its workstation (manually or autonomously), the robot will sense and determine its position relative to its environment. The robot will recognize the wall-plane, the boundaries of the present work section, and the boundaries of the neighboring work sections. Special elements in the work section (e.g. openings in the wall) will also be recognized at this stage. Other complimentary data sources, such as general information and local
data, can support the calibration process by adding relevant information about expected measurements and positions.

**Planning the task at the workstation** - According to the calibration data, the robot can relate a work plan to the actual environment, and roughly plan the relevant moves of the manipulator for the current work section. Before executing its task actions, the robot will present the work plan to the operator, who will examine it, correct it if necessary, and approve its execution.

**Fine calibration** - While executing the task, fine calibration will be performed during each cycle of manipulator moves aimed at placing an element. During the calibration cycles, sensors will collect accurate data on the end-tool's immediate environment. Based on these data, the robot will update the manipulator trajectory and move the element closer to its target position. In this iterative “Sense-and-Act” process, the sensing range will be gradually reduced, thus increasing the accuracy of the data collected. As a result, the manipulator moves for setting of the element will be more accurate.

3. **PRINCIPLES OF THE METHOD**

   The suggested method is based on the three following principles:

   **Close reference planning** - Planning of manipulator movements at a specific workstation is performed only after the robot is stabilized in its position. This means that there is no need to have advance knowledge of the surroundings' details nor is there any need for an accurate navigation system. Moreover, there is no need to prepare the building design as a basis for planning the robotic work. It is helpful, though, to use the building plans as guidelines in order to identify repeated elements, thus facilitating the definition of the workstation environment.

   **Local calibration** - A focus is placed on the calibration of the robot in relation to its close environment, after stabilizing at the workstation. This principle enables the neutralization of the effect of stabilizing errors on the accuracy of the task performance. This type of calibration must integrate various types of sensors for short-range recognition of the robot's surroundings, in a satisfactorily accurate and detailed manner.

   **Continuity** - The performance of each work cycle is derived from the performance of the preceding cycles, i.e., when setting a tile to a wall, its exact position will be realized relative to the position of the tiles already set, and not based solely on pre-calculated coordinates. To achieve this, special sensory devices must be developed and specially adapted to each task.

4. **TILE SETTING END–TOOL**

   The heart of the “Sense-and-Act” method is the “fine calibration” stage, which provides the expected accuracy required for the task. Development of a sensory device, which will be appropriate for the end-tool's accurate final moves, must be customized to the specific characteristics of the task at hand. Due to its extreme accuracy requirements, tile setting is one of the most complex construction tasks that can be performed by robots.

   The suggested tool consists of a suction gripper, a CCD camera, and five laser line projectors. The CCD camera is mounted, as part of the end-tool, in such a way that it views the corner of the gripped tile. Each laser projector projects its light in an oblique way, as described in Figure 4.

   ![Figure 4. A single laser beam relative to the CCD camera.](image)

   Projecting the laser line over the joint between two tiles produces an image of a broken line, as demonstrated in Figure 5.
The proposed sensing system identifies the broken section of each line (method not described here) and measures its length in pixel units (denoted $\Delta i$ where $i=1...5$ in Figure 5). The system then calculates the differences between the breaks for several specific pairs of lines. The deviations in the position of the gripped tile are proportional to the following differences:

- “Angular deviation” $\propto (\Delta 5 - \Delta 3)$
- “Horizontal deviation” $\propto (\Delta 3 - \Delta 1)$
- “Vertical deviation” $\propto (\Delta 4 - \Delta 2)$

After calculating the above deviations, the system commands the robot to correct them. This cycle of “Sense-and-Act” is repeated several times; each time, the gripped tile is moved closer and closer to its final position on the wall.

This sensing method is suitable for the typical situation of setting a new tile adjacent to three other, already set, tiles. The boundary cases, i.e., the first row and first column of tiles, must be solved manually. The robot operator will then set the first row and the first column of tiles as guidelines for the robot.

5. EXPERIMENTS

Full-scale laboratory testing was performed on the proposed sensing method (Figure 6).

An end-tool was built and tested in order to determine its ability to accurately detect deviations. The correction of linear deviations was tested separately from the correction of angular deviations. For calibration purposes, a gripped tile was set in its final position on the wall with negligible errors, and at a distance of 3 mm from its neighboring tiles. Then, the tile was positioned at a starting point located 60 mm from the wall, with known deviations of 20 mm in the linear case and 3° in the angular case. Several scenarios were tested that differed in the number of iterations and closing ranges performed until setting of tile in its final position. The resulting error was calculated by comparing the actual final position of the gripped tile with the calibrated final position.

The experiments revealed that:

- The attainable error for the linear correction was 0.2 mm. This error is perfectly acceptable.
- The attainable error for the angular correction was 0.3°. This error seems to be unacceptable.

Further improvements of the end-tool, based on an additional CCD camera and laser projector, can improve the angular accuracy to an acceptable error of 0.1°. Moreover, the same tool can also measure its own distance from the wall with an error of merely 0.5 mm.

6. CONCLUSIONS

Planning and executing the arm movements of a construction robot based on the building design is a most technologically demanding process. In contrast, a robotic system that would operate with no need for detailed pre-planning would be less technologically demanding and may, therefore, be easily developed during the early stages of the integration of robotics into the construction field. The suggested “Sense-and-Act” process eliminates the need for high accuracy when positioning the robot in its workstation, a fact that saves time and leads to a greater economic feasibility of the system. The “Sense-and-Act” scenario is simple and may indeed become a reality, as a midway stage in the development of more advanced robotic systems in construction.

An essential component of the “Sense-and-Act” method is an end-tool that is able to accurately perform the “fine calibration” stage. This paper presented the basics of such an end-tool designed for the task of tile setting, and,
following its satisfactory performance, demonstrated the feasibility of the “Sense-and-Act” method.

7. REFERENCES


Web-based an Emotion-Responsive Color Adaptation Process for Interactive Virtual Building Model

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ABSTRACT: The primary objective of this research is to realize an adaptable online architectural virtual reality (VR) model whose color attributes can be changed dynamically according to the identified emotional state of the user. We believe that the current approach to developing electronic based design environments is fundamentally defective with regard to support for multi-person multi-modal design interactions. This paper outlines new facilities within ubiquitous media spaces supporting embodied interaction between human-emotion and computation. Also, this paper addresses how to capture a specific user emotion through the web and use it for modifying architectural VR model mainly for its color adaptation. This adaptation process consists of three phases: 1) identification of the user emotional state projected onto the selected paintings 2) translation of the extracted emotional keywords into a pertinent set of colors 3) automated color adaptation process for the given VR model. In this paper, we introduced a method of using well-known paintings and their variations to derive online viewer emotional state which can be utilized to find a new color coordination scheme reflecting the identified emotion. This color harmony scheme can provide a useful information for a dynamic color adaptation for the objects embedded in the given VR model. The outcome of this study could enable an interactive and dynamic architectural VR model supporting emotion-responsive interior design simulations or the realization of an architectural environment where interior colors are changed according to the captured mood of the occupant.

KEYWORDS: Emotion-Response, Virtual Reality Model, Color Adaptation

1. INTRODUCTION
With technological development, space design has become more complex. This complexity has placed greater burdens on the Architect designer and created the need for specialists to support particular aspects of design. “Ergonomics” or “Human factors” is concerned with designing to meet the needs of human users. It draws on disciplines such as psychology and physiology for information and techniques. Part of the emotional ergonomic contribution to design is new research on how particular aspects of the built environment affect people (Bennett, Corwin. 1977). From the human factors to building space, a smart environment is one that is able to identify people, interpret their actions, and react appropriately. Thus, one of the major building blocks of a smart environment is a person identification system (Alex Pentland and Tanzeem Choudhury. 1999). As Japan Sensibility Marketing Research (Kunio Sato, Tesuya Hirasawa, 1996) suggested, emotional product industry is continuously progressing and draws attentions from various domains. An emotion-responsive interface is becoming indispensable in the cyber space for enhanced immersion and satisfaction.

To recognize human emotional state, the Human-Computer Interaction (HCI) is becoming more and more graphically orientated. The evolution of virtual space or VR has led to an innovative human-computer interaction medium with the potential to present the ‘ideal’ interface between users and computer generated synthetic environment. In this context, the advance of Virtual Reality has influenced diversified industries all over the world. Visual elements are undoubtedly the major media for constructing VR model. VR offers an almost unlimited space and it can represent and provide interactions in real-time (Kalawsky, 1998). The majority of virtual interfaces are designed to represent existing physical spaces or structures. However, VR systems are also very powerful for visualizing and interacting with large or abstract multi-dimensional environments (Kalawsky, 1993). Various tasks in architectural practice, especially design process, are influenced by the digital revolution through the increased use of computers. Ironically, various objects in cyber world are also becoming ‘architectural’ with the increased popularity of the 3-D simulation environments for intuitively constructing and navigating...
information space. In response to the growing demand, researchers set out to build interactive virtual space capable of being updated according to the user-specific information. Virtual space, seen not only as a technology but also as a mode of experience, brings 3-D objects which traditionally have been described and represented in an abstract way. The importance of communicating affective information is often ignored in interaction design. One of the most important criteria of an interactive interface is to give the user a chance to have a vivid experience with it. Therefore, it is obvious that the pursuit of emotion-associated VR design as a part of user-oriented interfaces will be getting more attention.

2. WHY ADAPTIVE VR MODEL?

If a computer can recognize human emotional state and react accordingly, we might think it has a certain level of intelligence. But in reality, this still is a part of science fiction. It is clear that not a single human can completely recognize their own deep emotion, actually in many instances, people cannot even recognize their own emotions. Internal feelings could remain private as long as we want them to be that way or if we sufficiently conceal them from being known to others. In this case, the external recognizers can only observe or reason about the feelings of others, which always are subject to some uncertainty. Despite this uncertainty, people want to know about each other’s emotion to communicate useful feedback. The partial goal of this research is to give computers cognitive capabilities similar to those that people have so that they can respond to a set of perceptual stimuli.

The process in which the colors of an interior space are dynamically changed according to a characteristic affective response of a user can potentially have at least dual purposes. Firstly, it could be used as a simulation tool for interior color design considering adequate color coordination required for the functions and placeness of a specific architectural space. For instance, an operation room in hospital is normally designed with white or green colors to invoke clean, calm, cold, and intense feelings required for the room functionality. This color coordination process could be simulated on-line with the proposed system in this research. Secondly, emotion-responsive interior space might be possible by utilizing controllable architectural components such as walls, floor, and ceiling the color of which could be changed depending on the occupant’s mood or emotional state. If this visionary scenario is implemented, a therapeutic interior color adaptation will be possible lessening, for example, a depressive mood with complementary color scheme suggested by the system in this research.

3. ASSESSMENT METHODS OF EMOTIONAL SIGNALS

According to the researches on human senses, our all five senses can be connected with those various signals such as physiological signal, bio-chemical signal, psychological signal, and behavioral signal. The data on human emotion is derived from these human senses (i.e. visual, auditory, olfactory, tactile, and taste). For instance, the physiological signals for various visual stimuli can be acquired using EEG (ElectroEncephaloGraphy), ECG(ElectroCardioGram), GSR(Galvani Skin Resistance), RSP and PPG(PhotoPlethysmoGram). Both measurement instruments and the systems which can manage, analyze, and evaluate the acquired signals have been developed. There also have been the development of an optimal bio-signal measurement method along with emotional criteria using psychological, linear and nonlinear chaos analysis methods. With the information on these preceding researches, ‘up-to-date’ emotional data analysis systems could be summarized like the one shown in Figure 1 (Affective Computing Research Group, MIT Media Lab, 2000).

![Figure 1. Assessment methods of human emotion](image-url)

4. STATUS OF EMOTIONAL SYSTEM TECHNOLOGY

An effective human-computer interaction allows emotional information to be communicated by the user in a natural and comfortable fashion. Emotional information also somehow needs to be recognized by the computer to support genuine interactions. At the MIT’s Media Lab, researchers are performing studies to give computers a
capability of understanding natural modes of human communication. Those researches include the interpretation of signals such as facial expression, vocal intonation, muscular movement, gesture, respiration, and even autonomic nervous system signals. Groups of sensors are designed to track user behaviors that might signal frustration and to relate the user behavior with the current state of the computer. The Media Lab emphasizes that sensors are important part of an ‘Affective Computing System’ because they provide information about the wearer’s physical state or behavior. It is discussed that they collect data in a continuous way without having to interrupt the user. Several projects in sensing which influenced our research are listed below on Table 1 (Affective Computing Research Group, 2000).

In this research, we studied visual stimuli for measuring emotional states based on the protocols for necessary experiments. In Figure 2, we marked bold lines and shadings on the elements we selected as the elements for our proposing emotional measurement system. The graphical structure itself is organized hierarchically based on the AIP cube (Zelter, 1994) to represent various technologies involved in VR. Our target VR system, mainly for demonstration purpose, is using a ‘monitor’ for visual display device in ‘presence’ category, ‘attribute and task modeling’ as a kind of object modeling in ‘autonomy’ category; a ‘mouse’ as gesture device, and ‘selection image’ as a method in ‘interaction’ category (Figure 2).

![Illustrative genealogical framework of VR technologies (Lee, 1997)](image-url)
Table 1. Types of emotional system technologies (Affective Computing Research Group, MIT Media Lab, 2000)

<table>
<thead>
<tr>
<th>Type</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affective Carpet</td>
<td>This deformable surface made of conductive cloth and conductive foam detects continuous pressure with excellent sensibility and resolution, and re-expresses the applied pressure musically.</td>
</tr>
<tr>
<td>Affective Jewelry and</td>
<td>Wearable jewelry and other clothing designs with embedded sensors for sensing accessories</td>
</tr>
<tr>
<td>Accessories</td>
<td>physiological changes associated with emotions</td>
</tr>
<tr>
<td>Expression Glasses</td>
<td>A wearable device which allows any viewer to visualize the confusion and interest levels of the wearer.</td>
</tr>
<tr>
<td>Frustration Experiment Design</td>
<td>A psychological experiment designed to elicit a “frustration response”, and to synchronize computer events with multiple channels of physiological data used to collect data for the frustration detection study.</td>
</tr>
<tr>
<td>Smart Shell</td>
<td>When a person is going to be at a “burned out” performance level, this system can it help motivate the person.</td>
</tr>
</tbody>
</table>

5. SCOPE OF THE SYSTEM DEVELOPMENT

The components and processes for the emotion-responsive VR systems developed in this research are as follow.

Construction of visual stimuli database containing various pieces of visual art and images derived from well-known paintings providing necessary stimuli for emotional measurement based on the experiment protocols.

Extraction of emotional key word and the identification of color coordinate key words based on the tone and brightness of the selected painting by the user.

Establishment for an emotional color palette that determines a set of colors for VR adaptation. This process is done by using Expert Color Coordinate System based on a series of built-in heuristic rules to coordinate the colors of the participating objects in the target VR space which are floor, wall, ceiling, and furniture.

Construction of an adapted VR model by changing colors of those objects selected in the virtual interior system modeled by 3D Max and EON Reality Studio using an adaptive user interface provided on the web.

6. COLOR PALETTE - KEYWORD IMAGE SCHEMA

When people see a certain combination of colors embedded in an image, a common feeling could run through their minds. Based on the research that maps adjectives with these images and colors, a scale has been developed such as the Key Word Image Scale. With this scale, three axes have been introduced for obtaining an objective evaluation uninfluenced by value judgments based on personal preference, or by the context of assessment. The words and colors located at the same point along the warm-cool and soft-hard axes have the same images; it is the image that constitutes the connections between the word and the color. Theses image words are not only applied to colors but also can be applied to shapes, patterns, materials, interior design, fashion, and product design by providing a way of organizing images in a psychological view point. (Kobayashi, 1990)

![Figure 3. Keyword image scale (Kobayashi, 1990)]
7. EXPERT COLOR COORDINATION SYSTEM (ECCS)

We propose ECCS an Expert Color Coordinate System in the VR space based on Kobayashi color image scale. In this research, it’s focus is a limited set of objects in the target VR model such as floor, wall, ceiling, and furniture. A suggested emotional color palette extracted through the visual image stimuli is needed to be coordinated for each of those architectural components to change the color attributes of the given VR model. ECCS is automatically coordinating colors for each of the objects in VR space based on the inference system built upon expert interior designer’s knowledge and experience.

ECCS is a rule-based color coordination system allowing knowledge to be represented as a set of heuristic rules which can specify a set of actions to be performed for a given situation. There are some exemplary heuristic rules for the research. For instance, how to coordinate the color of each object in the VR house interior model could be ordered by brightness of the colors. Usually, dark color is applied to floor and light color goes to ceiling. Unlike the first stage of the research where the emotion system has an emotional keyword from color scale, ECCS supports mainly the second stage of extracting color coordinate key words to establish the final color palette.

Before using ECCS, the user needs to decide whether or not this automated decision support tool should be used. When user does not want to use the system, he/she can either manually allocate colors to the objects or just leave the task to the random color coordination algorithm. In case the user manually changes the color of each object, the color harmony is out of his/her own color preference. When ECCS is selected, a specially arranged color harmony is expected to emerge out of the given emotional color palette.

Figure 4 illustrates the mapping between the selected emotional key words & color coordinated key words (i.e. natural, romantic, clear) and the corresponding color palettes. Each color in the palette is represented in CMYK values. Between the second set of images and the color coordinated palette, four different types of lines are marked to differentiate four adaptive objects in the target VR model. Each of them is also connected to a certain color in the palette.

8. PROPOSED EMOTION INFERENCE PROCESS

A user selects favorite image from the first set of images prepared from well-known paintings which have distinctive emotional implications. The user would interact with the system through a mouse event to select an image. Each of those posted images will have emotional keyword possibly backed by an on-line survey on the relationships between visual cognition and affection.

Figure 5 shows the images chosen for the first set of visual stimuli to extract emotional keyword. It shows different paintings tagged with emotional keyword such as natural, romantic, clear, casual, elegant, cool, dynamic, classic, and modern. It also shows the color coordinate keywords elaborating the subtleness of the proposed emotion inference process.
These second set of images are prepared by a systematic color tone variations of the chosen painting necessary for deriving a coordinate color combination. The color tone variation process is based on different balance levels described on the twelve-part color circle; ranging from the primary colors (yellow, red, and blue) to the secondary ones (orange, green, and violet). A tone has three ingredients such as shadow, mid-tone and highlight. Each of the ingredients has the color levels which are consist of cyan-red, magenta-green, and yellow-blue.

10. EXEMPLARY DEMONSTRATION OF THE SYSTEM IMPLEMENTATION

1. Implementation process
Figure 6 demonstrates an overall process of the proposed emotion-responsive Virtual Reality model focused on color adaptations. This process starts from the log-in point and ends its cycle when the user experiences or sees the adapted virtual reality model. In between, there are multiple steps to be followed such as the interpretation of the emotion-associated painting chosen by the user, the identification of the user’s emotion through the extracted color coordinate keywords using tone-varied multiple images for the chosen painting based on Kobayashi image keyword scale, a random or ECCS supported color coordination with the derived color coordinate palette, and finally, an automated color adaptation visualization process for the target objects in the original virtual model.
Figure 6. Activity diagram showing the proposed system’s internal process

2. 3D MAX – 3D SPACE MODELING
To build an initial 3-D construct as the basis for the virtual reality model on the web, we used 3D MAX software. Figure 7 shows a snapshot of creating 3D objects in the interior space of an imaginary house. Those objects are internally organized in a hierarchy for further modification or changes of colors. (Figure 8)

Figure 7. 3D modeling of interior objects

Figure 8. Hierarchical modeling tree of the created objects

3. EON Reality Studio – Adaptive simulation
As for the VR implementation environment, we chose EON Reality Studio for maximum performance and easy integration with the web environment. Figure 9 and Figure 10 show the exemplary processes where the created 3D objects are imported and further processed to become VR enabled EON objects the attributes of which are eventually manipulative on the web. Figure 11 and Figure 12 demonstrate object color specification and the final VR simulation process.

HTML documents are designed to display the first and the second sets of image stimuli and to obtain a user’s response to them. To modify the color attributes of the chosen 3-D objects such as floor, wall, ceiling, and furniture, we generated Event
nodes (shown on the left in Figure 13) which are embedded in a HTML document and associated with event Scripts and Objects. From this nodal representation of a virtual model provided by the Eon Reality Studio, a mouse click action on any of the ‘Event’ nodes (N01 –N07) can trigger the execution of the corresponding event Script to redefine color attribute for each of the 3-D objects represented as a material.

11. ADAPTIVE VR INTERFACE

As a demonstrative system implementation, we constructed a web-based emotion-responsive VR interface. In the beginning, user passes a log-on process by typing in his/her ID and password (Step 1). Secondly, the first set of visual stimuli shows up for the user to select an image out of them (Step 2). From the chosen image, a series of tone-differentiated images are displayed in the second visual stimuli interface for user’s selection (Step 3). The emotional keywords extraction and color coordination for VR simulation are processed internally. Eventually, the user is able to see the effect of his/her actions by experiencing an emotion-adapted virtual reality model in real-time (Step 4).

Figure 13. Node Tree describing the color modification process of the EON objects and corresponding source codes for the selected nodes
12. CONCLUSIONS

This study has suggested that emotional intelligence, being based on the emotional keyword-driven color schema necessary for magnifying the role of emotion in human intelligence, can be a subset of machine intelligence and that the way for man-machine interaction resembles the mode of inter-human interactions.

As an attempt to make an interactive and adaptive virtual space, this research tried to construct a methodological frame work to develop a user-centered VR system allowing interactions between the user and a virtual space beyond the conventional limitation of just imitating real world or using a straightforward web interface. The primary requirement this study tried to fulfill was to maximize the sense of emersion and satisfaction for using VR objects on the web, which has been partially explored through a color-adaptive VR model based on the identified user’s emotional state.

The advantages of the proposed emotion-responsive and color-adaptive virtual reality model are connected with its capabilities to invoke users’ active involvement and to explore a potentially new way of interior design in the future. The research has been theoretically based on the principles of emotion and colors as well as the emerging discussions on the emotion-responsive virtual space. The research process itself has been directly formulated through understanding the relationships between these theoretical bases. Eventhough the proposed set of keywords representing emotion-color relationships identifiable through a cognitive survey might not best reflect potential users’ emotional state, it could be, at least, a starting point to develop a human-centered virtual reality system supporting dynamic interactions between users and virtual spaces in the future.
13. REFERENCES


3D Simulator of Modular Building Assembly by Automated Cranes

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ABSTRACT: This paper presents a new construction method based of modular buildings. In this new method, the buildings are to be assembled from their modules using automatic means such as robots or/and automated cranes. A Computer Integrated Construction (CIC) architecture has been proposed to achieve the modular construction covering all aspects from the design until the assembly on site. The system is modular: design, planning and simulation tools are integrated in a graphical user interface. The 3D building design is performed by special tools developed for this purpose. Then planning tools calculate automatically the modules assembly sequence and the path to place the modules by the crane. These trajectories are animated with the developed simulation tools to ensure secure paths and to correct the erroneous ones. Finally, an automatic gantry crane developed at the Laboratory is used to test the automatic modules placement.

This paper is dedicated to describe the simulation tools. Two crane simulators for a gantry and a tower crane, a specific programming language and a program editor have been developed. A program contains a list of instructions with the trajectories that can be automatically generated by a planning tool or manually by the operator using the program editor integrated in the simulator. The user can select different velocities to run a program and can execute a program instruction by instruction or in continuous mode. A toolbar shows the position of the grasping platform at each moment and the current instruction in execution. The user can also move manually the simulator by a graphical pendant that has buttons to move each joint individually. This program can be used in the laboratory gantry crane to place the modules to assemble a particular building setup.

KEYWORDS: 3D animation, crane simulation, robot programming language, modular building, CIC.

1. INTRODUCTION

Traditional methods of house-building are usually based on manual techniques which are slow and expensive. New construction methods based on modular buildings will not only increase productivity, but also improve work safety and reduce the numerous hazards of nowadays work in building sites. The modules are prefabricated in a well controlled environment and the transported to the site. In this new method, the buildings are to be assembled from their modules using automatic means such as robots or/and automated cranes [Balaguer].

A Computer Integrated Construction (CIC) architecture has been proposed to achieve the modular construction covering all aspects from the design until the assembly on site. The system is modular, object-oriented, flexible and easy to extend. A graphical user interface integrates design, planning and simulation tools. The process starts with the 3D building design performed by special tools developed for this purpose. Then several planning tools are used to calculate automatically the modules assembly sequence. These modules will be placed on site by an automated crane. According to the established sequence the path to place the modules by the crane are also calculated automatically. These trajectories are animated with the developed simulation tools to ensure secure paths and to correct the erroneous ones. Finally, the automatic gantry crane developed at the Laboratory is used to test the automatic modules placement.

This paper is dedicated to describe the simulation tools. Two crane simulators for a gantry and a tower crane have been developed. A specific programming language has been created to write the task, which has to be executed by the crane. A program contains a list of instructions with the trajectories that can be automatically generated by a planning tool or manually by the operator using a text editor or the program editor integrated in the simulator. The simulator executes the program to visualise the assembly sequence. The user can select different velocities to run a program and can execute a program instruction by instruction or in continuous mode. A graphical pendant shows the
position of the grasping platform at each moment and the instruction in execution. The user can also move manually the simulator by a dialog box that has buttons to move each joint individually. The editor permits to write or modify a program and make sure that the program is error free. This program can be used in the laboratory gantry crane to place the modules to assemble a particular building setup.

2. SYSTEM ARCHITECTURE

The modular construction system is formed by a set of applications or modules and a group of data libraries, which are integrated in a Computer Integrated Construction (CIC) scheme [Diez 2003]. Applications or tools are grouped by their function in design, planning and simulation tools (figure 1 shows a schematic representation of the software architecture). The system is modular, object-oriented and flexible. New tools can be added to improve the system performance and to extend its capacities.

![System architecture](image)

AutoCAD has been selected as the main software package, because of its widespread use and because it incorporates several development tools. Different technologies are available in AutoCAD to design and implement new AutoCAD-based applications [McAuley]. The chosen development tool for the implementation is the AutoCAD Runtime Extension (ObjectARX) [Owen Ransen]. ObjectARX is an Application Programming Interface (API) that contains a set of C++ classes and functions. A group of new functions have been created in order to enlarge and adapt AutoCAD to the problem specification. To facilitate the use, these additional software utilities are included in the AutoCAD menu bar.

A central database contains the information that can be accessed by applications through a graphical user interface. The AutoCAD DWG format is the file that store graphical data and other non-graphical information. AutoCAD is used as the main graphical user interface. Applications are created using ObjectARX and integrated into AutoCAD.

The designer produces the 3D building design by using special tools developed for this purpose. Modules, that form the spaces of a building, are included in the drawing by the designer. Dialog boxes guide the user to select the modules specifications contained in a library. Another tool, automatically, calculates the number, dimensions and characteristics of the modules needed to erect a building from the 2D building drawings [Diez 2000]. These data are saved into the building database.

Planning tools read data produced in the design stage. Then, these data are analysed in order to calculate production schemes, modules assembly sequence, transportation, etc. A planning applications determine the order in which modules are assembled and calculate automatically the trajectories that automated devices, such a crane, has to follow to place modules in their final position [Padron]. These paths, calculated automatically with planning tools, can be tested in a simulator before executing the commands in the real crane. The simulator is integrated with the rest of applications in the same graphical interface. Crane simulators, program editor and programming language are described in the following sections.

The designed and prefabricated modules are expected to be placed on site by an automated crane. An automatic gantry crane developed at the Laboratory is used to test the automatic modules placement [Abderrahim]. During the assembly process, the crane follows the paths previously calculated in the planning tool. The commands sequence is written in the same language used in the simulator.

The system includes a group of libraries, which contain information and data of the system: the module characteristics, the construction criteria, the modular division specifications’ information, the structural specifications, etc.

3. SIMULATION TOOLS

Simulation tools are applications written in C++ object oriented language using ObjectARX and MFC (Microsoft Foundation Classes) libraries. They are compiled as DLLs (Dynamic Link
Library) that can be launch into AutoCAD at any moment.

Tower and gantry crane simulators, a programming editor and a programming language are the tools developed to simulate the modules automatic assembly.

3.1 Crane models

Two cranes models have been implemented: a gantry and a tower crane. Nevertheless, new types of cranes can be added because the system is modular. The cranes are drawn with prismatic models to represent the main structures and a line to simulate the elevation cable (see figures 2 and 3). These models are parametric, where the main crane dimensions (length of bridge or the jib, crane height, etc.) can be selected before drawing the model.

Crane dimensions are internal data to determine the crane reach. Position and orientation of the grasping tool determines the configuration of the crane. Current joint value is calculated via inverse kinematics. Graphical elements are displayed in their correct position and orientation calculating the homogeneous matrix corresponding to these values. Joints values are calculated in intervals to visualize a continuous movement during the simulation.

• In the z axis, the vertical movement to rise/descent the module.
• A rotation along the z axis to orientate the module in xy plan.

Tower crane is drawn with the union of triangular and rectangular prisms to form the tower and the jib, lines to draw the cables that support the jib and counter-jib and a line with variable length to represent the hoisting cable (see figure 3).

Four movements have been implemented to simulate tower cranes:
• Slewing of the jib over the tower.
• Trolleying over the rails.
• Hoisting of the load.
• Rotation of the load along a vertical axis to orientate the modules being handled.

The joints can be moved separately and imitate the movement of a real tower crane using a joystick. It is also possible to perform other movements, such as linear movements, using a programming language. In these cases, two or more joints are moved simultaneously.

3.2 Programming language

There is no universal programming language of robots, each manufacturer develop one specific for their products. A robot programming language should be easy to learn, similar to computer programming languages and does not change over time [Lapham].

The movements of a gantry crane (Cartesian robot) or a tower crane (cylindrical robot) are well known. When a module is placed in its final position, it is part of the environment. The paths are different for each module. According to these reasons, the language needed to program cranes should be simple and adaptable to different types of cranes.

Figure 2. Model of a gantry crane

Gantry crane have three movements implemented across Cartesian axes. It is possible to incorporate a fourth movement, a rotation of the grasping tool, to orientate the modules (see figure 2). These movements are:
• In the x axis, a linear movement of the trolley along the bridge.
• In the y axis the translation of the bridge.
The developed robot programming language has a simple syntax. A program is a text file containing a list of sentences. Each line contains a command followed by parameters if it is required; each command ends in a semicolon:

```
command_name [(par1, par2, par3)];
```

Language commands can be classified in different types:

- **Absolute movement to destination:** movement to point indicated in the parameters (*MoveTo, MoveJoints*) or movement in a Cartesian axis to the coordinate indicated in the parameter (*MoveToX, MoveToY, MoveToZ*).
- **Relative movement:** movement in a Cartesian axis from the current position to the distance indicated in the parameter (*MoveDistX, MoveDistY, MoveDistZ*). 
- **Joint movement:** movement of each joint individually. The movement can be absolute (*RotateJibTo, MoveTrolleyTo*) or relative (*RotateJibAngle, MoveTrolleyDist*). 
- **Tool operate:** to grasp (*Set*) and ungrasp (*Reset*) the modules.

An example of programme is the following:

```
MOVETO (1.90, 5.90, 1.60);
MOVETOZ (1.60);
SET ;
MOVETOZ (1.60);
MOVEJOINTS (0.90, 2.10, 1.60);
MOVETOZ (1.10);
RESET ;
MOVETOZ (1.60);
```

The crane goes to the supply point, then grasp the module. The module is raised and transported to the final location. The module is released and the crane moves back.

### 3.3 Program Editor

A program is a text file containing a sequence of commands. This file can be written directly in a text editor, can be generated automatically using a specific application or can be edited in a robot programming editor.

One of the planning tools (see figure 1) can generate automatically the program from the design data and the crane specifications. This application calculates the assembly sequence and the path that each module has to follow from the supply area to the final point avoiding collisions. This is the main source of written programs.

![Figure 4. Program Editor](image)

A program editor has been created to develop or modify programs. This editor is integrated in AutoCAD with the rest of applications and has an appearance similar to other windows applications (see figure 4). Commands are selected from a list and the editor automatically inserts the adequate parameters. The current position of the crane can be read directly from AutoCAD.

### 3.4 Graphical User Interface

All applications are integrated in AutoCAD, so AutoCAD is the main interface. Tools developed work like native AutoCAD commands, they are accessible from menus or command line.

![Figure 5. Graphical User Interface](image)

The main features of the graphical interface (see figure 5) are the following:

- Specific menus integrated in AutoCAD which permit the applications use.
- Toolbar to launch program editor and run simulations.
- Program editor.
Graphical pendant to handle every type of crane. This dialog box allows to move each joint individually, shows the current running instruction when a program is executing and shows the current position of the grasping platform.

4. SIMULATION EXAMPLES

To run a simulation the user selects this option from the menu, the toolbar or typing the instruction in the command line. Then the user selects the program previously created. There is two execution modes: instruction by instruction or continuous. Finally, the user select the speed of the simulation. To visualize the simulation, the application updates position and orientation of movable parts (crane joints and modules) at regular time intervals.

4.1 Gantry crane

Figure 6 shows four moments of a simulation sequence. The instructions list are written in the previous section. The assembly starts when a module arrives to the supply area (figure 6 upper left). Then the crane moves to this position and grasp the module (figure 6 upper right). The crane moves the module along the calculated path (figure 6 bottom left). Finally, the module is placed in its final position and the crane moves back (figure 6 bottom right).

Figure 6. Simulation sequence with a gantry crane

4.2 Tower crane

Tower cranes need to rotate the module to place it in a correct orientation, because the slewing of the jib over the tower. To perform a similar task like that shown in the gantry crane case, the following program is needed:

```
MOVETO (6.0,0.0,4.0);
TOOLORIENT (0);
MOVETOZ (2.0);
SET ;
MOVETOZ (4.0);
MOVEJOINTS (0.80,7.30,4.0);
TOOLORIENT (0);
MOVETOZ (2.0);
RESET ;
MOVETOZ (4.0);
```

The difference is the instruction ToolOrient which permits the rotation of the module. Figure 7 shows six moments of a simulation sequence. The assembly starts when a module arrives to the supply area (figure 7 upper left). Then the tower crane moves to this position and grasp the module (figure 7 upper right). The crane moves the module along the calculated path (figure 7 middle left) to the final position, but in a higher level (figure 7 middle right). Then the module descends (figure 7 bottom left) and finally it is placed in its final position and the crane moves back (figure 7 bottom right).

Figure 7. Simulation sequence with a tower crane

5. LABORATORY GANTRY CRANE

The automatic gantry crane developed at the Laboratory is used to test the automatic modules placement. The system was developed using a
commercial crane, which was modified by adding the adequate sensors, servomotors and an advanced control system [Abderrahim].

Figure 8 shows four moments of an assembly sequence performed by the laboratory gantry crane. The grasping platform goes to the supply area and capture the module (figure 8 upper left). Then the crane rises the module to avoid collisions (figure 8 upper right) and moves it along the calculated path to the final position, but in a higher level (figure 8 bottom left). Finally, the module is placed in its final position and the crane moves back (figure 8 bottom right).

6. CONCLUSIONS

The developed crane simulators present new tools to test the automatic assembly of prefabricated building modules. The outcome demonstrates the feasibility of the process of automation and shows how the system could assemble 2D and 3D modules, where all movements are tested first on the simulator. The integration of several applications in the same graphical interface facilitates the information interchange and reduces time for learning and using. The system can be extended or updated since one of the main features is modularity.

7. ACKNOWLEDGEMENT

This work has been supported by the EU project FutureHome under BRITE program with reference n° ER4-29671 and in close coordination with the IF7 Japanese program in the frame of the IMS trans-regional program. The authors would like to thank people who have helped in the development of this project, especially to E. Navas, L. Camaño, and J. Castro.

8. REFERENCES


A Concept Study on Wearable Cockpit for Construction Work  
- not only for machine operation but also for project control -  

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ABSTRACT: Construction work needs in many cases human sense and decision, and consist in combination of every task and machine. In this aspect it must be effective that an operator can proceed a project while she/he is managing and operating tasks and several machines at a site with just-in-time accurate decision by means of constant monitoring. The existence of human being however causes problems as human inefficiency, inaccuracy and occupational danger and strain. And simple extension of object in operation, from a machine to all tasks in a project, is afraid to result only in increase of work load for a person.  
The wearable cockpit aims total control of a construction project. This means extension of the concept “to a cockpit for project control from that for only operation of a machine”. This concept includes multi-operation of several machines and total management of all tasks at a site. In the concrete the wearable cockpit includes 1) a tele-operation system for multi-operation, 2) assistance of decision making inclusive of enhancement of recognizing ability in time and space, 3) optimal task ordering and 4) optimizing of machines.  
In this study we consider to apply a RFID system with AR technology to the enhancement of recognition inclusive of on demand visual communication. For task ordering and machine optimizing, analysis of time allowance in each sequence is considered. On the automation unfriendly sequence a tele-operation system is usefully applied. By means of these kinds of assistance an operator makes accurate decision timely. Besides the human decision making lightens difficulty and costs for filling construction up with automation.  
As a result of these considerations an operator can control a project accurately and efficiently with technology of wearable equipment.  


1. INTRODUCTION  
Inclusive of not only many private cars but also industrial vehicles, which include for example construction machines, loading machines and trains, vehicles play an inestimable role in present society. Therefore improvements and developments of vehicle have been occupying a large area in history of Industry. Mainly the working efficiency and in addition the easiness and safety of operation have been greatly progressing. Furthermore consideration on the environmental aspect has been already long taken into account, inclusive of environmental load, outward danger and aesthetic appearance.  
On-board operation is general as a driving mode of vehicles. Then we consider a driving space, which is usually called a cockpit even if it is not on an airplane or a racing car. A cockpit requires comfortableness and safety of an on-board operator. As a result an operator can continue driving accurately while she/he is feeling hardly any tiredness and strain. Many researches and developments have been executed and some of the results are already in practical use, for example “Ergonomic Innovation / Comfortable vehicle cabins [TNO]”, “The Workplace of Tomorrow / Futura II; concept study on mobile excavators [O&K]”.  
Now there is an “automatic drive” as the best mode of comfortable and safe operation. People can achieve the purpose to be quite free from occupational danger and strain without operation, and there is a case that the work efficiency rises up as well. Therefore this has been also regarded as, as it were, an ideal mode. But compared with factory machines which are fixed and whose objects and movements are relatively constant, a premise of “a vehicle moves itself” requires constant monitoring to surroundings and adequate
decision. As a result it makes the automating of vehicle difficult. Also it limited an automatic drive to a few opportunities of use. In fact it constraint us to say that an automatic drive is not practical enough but still in a level of assistance. It means, in the function of surroundings sensing (monitoring) and decision making, the technology does not catch up a total ability of human being yet. In the other hand, a concurrent elimination of driving pleasure and working opportunity with the removal of strain may cause a problem from humanistic or social aspects.

By the way, operation of a construction machine consists in combination with the other tasks and machines among all works at a site. In this aspect it must be effective that an operator can proceed a project with just-in-time accurate decision while she/he is managing and operating tasks and several machines at a site by means of constant monitoring. Yet there are many tasks requiring what is called human ability in the form of multitask activity, sensible sensing or decision making in construction works. The existence of human being causes problems as human inefficiency, inaccuracy and occupational danger and strain. And simple extension of object in operation, from a machine to all tasks in a project, is afraid to result only in increase of work load for a person.

Recent progress of robotics makes us possible to consider the application of this technology to human ability required tasks. One research direction is full replacement of works with a robot, the other is only assistance to human being of a robot who helps us to keep from danger and strain. The former is an application of an autonomic robot who has human ability, what is called a Humanoid, and the latter is an assistant of manual operation occasionally with a wearable robot who enhances human ability. A tele-operation belongs to the latter because a human being makes decision and operation. Incidentally in vehicle driving at present the applied humanoid robot still premises a tele-operation. This means that full automatic driving with a robot is not realized yet [Hasunuma 2002].

2. PRESENT DEVELOPMENTS ON CONSTRUCTION VEHICLE OPERATION

2.1. Improvements of driving situation

Construction vehicles have been improving in the cockpit for all human impressions in order that an operator can continue comfortable and accurate operation while she/he is feeling hardly any tiredness and strain. The measures in concrete are for example improvement of the seat, sound and light control, air conditioning, structure design for safety, betterment of panel layout, aesthetic appearance, environmental friendliness and so on. In addition to these spatial measures, considerations on comfortable and safe driving expand the aspects wider. For example an improvement of equipments inclusive of those for sure operating response, accurate monitoring and adjustment, better communicating situation. Additionally as well humanistic aspects which are for example those on clothes or health management, and social ones such as those on qualification system, reward, interval of rest.

2.2. Tele-operation

Besides the improvements of driving situation, technology for operation without boarding such as automatic control, tele-operation or monitoring by means of remote communication is surely improving. The object is also comfortableness and safety of an operator, which is the same as that of the present measures on cockpits. It enables an operator to perform her/his tasks from a convenient, comfortable and safe place. Aside from automatic control, progress of technology in radio communication, use of a satellite and virtual reality improves the performance of tele-operation remarkably. That in for example a suppression of time delay, a exact transmission of sensible human sense such as a tactile sense of finger, a development of high reality tele-operation by virtual reality and so on, enables an operator accurate monitoring, decision and operation, as if she/he were really on board. At the same time it frees her/him from occupational danger and strain, and precludes her/his mistake and trouble.

For tele-operation a special machine is normally prepared. Many of the parts are of course the same as those of a normal machine, therefore it is in many case prepared as an altered machine. Mainly the alteration on operation system such as a change of hydraulic system or an addition of a radio communication apparatus is necessary. It is not a rare case that the alteration costs, which are too expensive to recover in relative a few opportunities of using tele-operation, make us adopt alternative measures. For this reason there are developments for less or no alteration, for example that of applying an attachable operation unit or a humanoid robot on a normal machine.
3. STUDY ON APPLICATION OF PRESENT TECHNOLOGY FOR WEARABLE ROBOT

3.1. Background and Today of the progress
From another aspect that is on a purpose of utilizing human ability such as a general but suitable sensing and deciding, there is ordinarily a way of manual operation besides an application of a humanoid robot. Nothing is more efficient than human operation to display human ability so far as there is no danger or it is not in a bad situation. Then here comes a better way of wearing a robot, which keeps an operator from danger and makes the working situation better. It becomes more efficient when it covers her/him from human defect such as mistake and tiredness, when it reduces troublesomeness of mastering the operation, and in addition when it enhances human abilities for multitask, decision making, and sensing. The follows are main present research areas to answer the purpose of enhancing or recovering human ability.
- Embedded chips or systems
- Wearable computers
- Exoskeleton systems
These technologies are already being used in practice. Especially the ones for medical use are currently advancing. Augmented reality system on wearable computer, which assists us in visual and acoustic sense and partly memory by means of virtual reality technology, is expected to bear effective industrial use.
On the other hand wearable robot, which consists mainly of exoskeleton systems, is still now not used in practice. But some of the application are under practical consideration, for example that for enhancing or recovering our physical ability on demand.

3.2 Expected utility
The most expected functions in construction site are from one aspect monitoring of the situation and decision making, and another aspect prevention of tiredness and occupational stress (strain or danger). Monitoring usually requires all of human five senses (or six senses), especially visual sense. Therefore the utility of AR technology, before mentioned, is greatly expected on enhancement of visual sense. Generally the follows are some of the industrial utility of AR (Figure 1). [ARVIKA]

- Task indication of position and time in real sight
- Visual comparison between a plan and a present progression
- High visibility
  - No dead angle, Transparency through obstacles, Visualization of inner structure or underground
  - Clear sight in fog, darkness and dusty air
- Visual help for consideration
  - Visualization of temperature, humidity, air flow, smell, sound and others
- Visual check with the help of related data for construction materials and parts
- Pre-check of process and simulation of result
- Communication assistance
- Training
We can apply each of the utility directly to site management, machinery operation and monitoring of the situation. And in addition some computer technologies assist us in decision making and memory. These results enable a manager or an operator to preclude mistake and trouble, and to work comfortably and efficiently. Thereto the expected reduction of her/his tiredness results in prevention of accident.
From another aspect we can consider the utility of tele-operation besides that of AR, because wearable cockpit presupposes the technology for operation without boarding. In addition to the utility of tele-operation itself, possibility of multi-task should be mainly expected, which includes operation of several machines and control of additional work beyond operating. As a result an operator can monitor all objects at a site and control a project efficiently with technology of wearable equipment.
4. STUDY ON WEARABLE COCKPIT

4.1. Enhancement of sensing

Most of monitoring at construction site, which is all the time necessary, relays on human senses. Therefore a direct assistance in human sensing is effective at first. Especially many problems of unsatisfactory sight in construction works, such as danger of a crash, inefficiency and inaccuracy, make us expect greatly the technology of exclusion from obstructions in sight. Some of the technologies of visual enhancement are already being used in practice. These are for example a function of clear visibility in the dark, visualization of dead angle or backward sight. The practical technologies are however still now only through a fixed monitor. We are therefore now studying an application of AR technology to the enhancement of visual sense, in order to make an operator feel as if it were her/his real sight.

4.2. Enhancement of identification

Decision making needs an object to indicate clearly the situation in process. A visual instruction of work, such as a virtual indication of planned form of excavating in the operator’s real sight, and a process management by visual comparison are the examples. Besides the before mentioned method of enhancing human sense, an easy identification method of objects by picking up preliminary inputted data must be more effective for situation recognizing and decision making.

We are trying to apply an embedded system of RFID for this purpose. [Bock, Ashida 2002] Basic data of each object are preliminary registered in the chip and it is embedded in the object. Such an ability of RFID as on demand registering of the necessary data enables us to be free from a complicated data preparation or management which causes sometimes a so-called data cemetery. Additionally we can also rewrite the difference in situation between plan and process if necessary.

By the RFID system we can identify all objects in the radio effective distance at the same time on demand and recognize the specification of them quickly and easily. AR system can in addition indicate the visual situation such as the position, appearance, movement. Therefore a manager can take also an invisible object into account. On operator’s requirement, the system can relate an object to the more detail data automatically. From these aspects we can consider the RFID embedded system to be one of effective method that enhances our ability of identification for decision making.

4.3. Project control system

When we control a construction site totally and manage all tasks in a project, the working load increases according to the number of objects. The less working load increases, the more efficiently a project would be controlled. To lighten the load on an operator, each task must have some automated process in itself. On the other hand however a full automation in construction work complicates the system and needs high technology, therefore it limits opportunity for the application at present. Because a decision making sequence is difficult to automate, where human ability is required. In this aspect we are studying a system, that classifies tasks under the automatism and considers each allowance of time. And then we apply automatic systems on automation friendly sequences, for example a repeated task such as simple transportation by cranes or forklifts. These kinds of task need no continuous monitoring but only accidental alarms and an end signal of the sequence. We can in addition consider a partial automation in the same sequence, which includes for example both automatic transportation and manual adjusting of final positioning for the fixing.

We will make no effort to automate automation unfriendly sequences but analyze them as manual ones to result in minimum loss of time as follows;

1) Consider whole allowable time of each sequence in the rest of a project period.
2) Calculate the allowable time for decision making, which is difference between whole allowable time of the sequence and required.
3) Make an optimal combination in time with automated sequences and put the tasks in order.
4) Check the total loss in time and repeat the analysis

This system shows an operator the next necessary task in consideration of total efficiency of a project. She/He can make an accurate decision by this system without being puzzled. Priority of task is always repeatedly considered and the order is replaced if necessary. In addition this system can analyze an allowance of automated sequence as well. It enables us to consider minimum and enough performance of the
machine. We can optimize machines for better running and less load on environment.

As a result of these considerations an operator can control a project accurately and efficiently.

![Figure 2. Concept outline of the wearable cockpit.](image)

5. CONCLUSIONS

Construction work needs in many cases human sense and decision, and consist in combination of every task and machine. The wearable cockpit aims total control of a construction project. This means extension of the concept to a cockpit for project control from that for only operation of a machine. This concept includes multi-operation of several machines and total management of all tasks at a site. In other words, the wearable cockpit includes not only 1) a tele-operation system for multi-operation but also 2) assistance of decision making inclusive of enhancement of recognizing ability in time and space, 3) optimal task ordering and 4) optimizing of machines.

In this study we consider to apply a RFID system with AR technology to the enhancement of recognition inclusive of on demand visual communication. For task ordering and machine optimizing, the analysis of time allowance in each sequence is considered. On the automation unfriendly sequence a tele-operation system is usefully applied. By means of these kinds of assistance an operator makes accurate decision timely. Besides the human decision making lightens difficulty and costs for filling construction up with automation.

6. OUTLOOK

While the wearable cockpit enhances management ability of an operator, she/he controls all tasks in a project. She/He manages machines as if they were employees. She/He works her/himself as well. Surely she/he can not always control all tasks in a project alone but proceed them as optimal as possible. On the other hand we can expand our consideration in future into ubiquitous control of several projects.

We intend to progress our study further to realize this efficient project control in the direction of assisting an operator, that is, enhancing a human ability as a result. Be that as it may, because this study is still in the step of concept, we need to bring the system soon into practical study.

7. REFERENCES


The application of an Auto-stereoscopic Display in Design and Construction

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ABSTRACT: This study explores the application patterns of an auto-stereoscopic display (ASD) in architecture. An ASD set-up is exemplified to serve computer supported collaborative works (CSCW) and construction needs. The system is applied to both geometry- and image-based VR contents. A DTi 18.1” ASD is used for content illustration of still images and videos.

KEYWORDS: auto-stereoscopic display (ASD), 3D display, VR

1. INTRODUCTION

Architecture-related application of auto-stereoscopic display (ASD) is still limited. Most of the application are presented through a stereoscopic view of virtual data with an HMD. In reality, activities usually occur when no 3D modeling data are available. The recording and post-representation of the situation is a complicated task. The application of stereoscopic display can be seen in the reconstruction of crime scenes (Howard 2000), Internet video transmission (Johnson 2001), 3D TV (Kawowowska-Lamparska 2000), size (Kobayashi 1999), crane operations (Quek et al. 2000), and mechanical engineering (Tuokko 1999). Autostereoscopic display application can be seen in medical treatment planning (Christopher et al. 1999), volume rendering (Hubbold 1998), undersea imaging and measurement systems (Liu 2001), and 3D data viewing on the Internet (Uchiyama, 1998). The involvement of multiple observers is also feasible with these applications (Kitamura 2001). However, the capability of currently available computer systems may not be enough to deliver a truly 3D scene remotely. The influence of display devices on architectural data types and sources also remains to be studied.

2. RESEARCH PURPOSE

This study explores the application patterns of an ASD in architecture. An ASD setup is exemplified to serve computer supported collaborative works (CSCW) and construction needs.

3. VR TECHNOLOGY

3D display contents usually come from different types of sources that correspond to the outcome of the 3D modeling programs. To transfer a 3D scene to a VR format not only involves taking into consideration of the characteristics of the 3D data, but also preparing an appropriate display system for the data. Although the types of interaction can be categorized into VR, augmented reality, diminished reality, and mediated reality based on Steve Mann’s classifications, this paper emphasizes the common VR definition, which includes geometry- and image-based VR.

3.1 VR types

VR can be categorized into geometry-based and image-based types.

• geometry-based VR: This type directly transfers 3D geometries created in application programs to formats suitable for VR interface or interaction. Most of the geometric characteristics are kept and can be manipulated in 360 degrees by a mouse. A user can walk-through or fly-through a scene.

• image-based VR: This VR type applies images to simulate views of an object or a scene from different angles, as if the viewed is located at the center. Images can be stitched into panoramas or to objects for an off-center or toward-center inspection. No geometric object has to be created beforehand. Image-based VR usually provides better visual details because the pictures are of photograph quality.
3.2 Types of 3D VR display systems

Stereoscopic, autostereoscopic, and volumetric display are three types of illustration that can offer users a 3D sense of objects.

- **Stereoscopic:**
  - Anaglyph method: This method uses color or polarized lens to differentiate the images for the left and right eye.
  - Frame-sequential method: This method uses LCD shutter glasses to differentiate the display sequence of images for the left and the right eye.

- **Autostereoscopic:** This is similar to stereoscopic display, but no glasses are needed. An ordinary VR interface tracks the viewer’s orientation in order to display the corresponding contents from a computer. The track holder also determines what other viewers see. In group communication, the control of the viewport has to be passed around if anyone else wants to show his or her view. However, this type of content delivery does not necessarily meet the individual needs of interaction in group communication.

- **Volumetric:** This applies solid volume, multi-planar, or electro-holographic display to increase the depth of an image. This autostereoscopic display use of technology in architecture can be seen in multi-planar, parallax barrier, or directional projection. Currently used ASD methods are listed as follows.

  - DTi display (see Fig. 1): This was a lenticular screen to differentiate the images for both eyes. A user can perceive an optical depth of space when the eyes are properly positioned.
  - Synthgram display (see Fig. 1): The display screen is divided into nine regions for corresponding viewing orientations of an object. A user can perceive depth of space in more directions with fewer blind spots.

![Figure 1. DTi display, camcorder, and stereo lens (left); Synthagram display (right)](image)

Table 1. List of autostereoscopic display contents

<table>
<thead>
<tr>
<th>targets</th>
<th>hardware (retrieval devices)</th>
<th>Sources of data</th>
<th>Image types</th>
<th>content creation software</th>
<th>Auto-stereoscopic interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR still images</td>
<td>Pair software camera shots</td>
<td>still computer image pairs</td>
<td>fixed views</td>
<td>any 3D renderer</td>
<td>DTi</td>
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<td>VR panorama videos</td>
<td>Panorama renderer Camera shot stitches</td>
<td>Dewarped panoramas still computer image sequence</td>
<td>panorama views</td>
<td>ArchiCAD ArtRentis 3D Studio</td>
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<td>VR panorama videos</td>
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<td>DTi</td>
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<td>RW still images</td>
<td>Pair camera shots</td>
<td>still image pairs</td>
<td>fixed views</td>
<td>DTi</td>
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<tr>
<td>RW video</td>
<td>DV camcorder with Nu-View stereo lens</td>
<td>parallax analog video signal</td>
<td>fixed views</td>
<td>DTi</td>
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<tr>
<td>RW panorama videos</td>
<td>Paradome Panashot lens attachment and NetVision 360</td>
<td>parallax analog video signal</td>
<td>Panorama views</td>
<td>Panashot DTi</td>
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RW: real world
4. VR AND REAL WORLD DISPLAY OF OBJECTS AND SCENES

VR format and ASD need to be incorporated into the architectural modeling process for the easy setup of an application environment. Both geometry-based and image-based VR types can now be used in an ASD mode (see Tab. 1). Geometry-based VR requires the use of a specially designed lens to separate the views for each eye. Views can be recorded as a single image pair or as a mixed video signal. The lens can be pointed toward the orientation as generated to generate a panorama-like experience. Similar to image-based VR, pictures are taken at a distance that is about equivalent to the length between the eyes (8 inches in general) (see Fig. 2 & 3). Adjustment has to be made to paired panoramas to generate an autostereoscopic view from all angles. The ASD and a lens can be connected by cables or through the Internet. A wireless connection is also possible using a 2.4 GHz AV sender and receiver.

4.1 The advantages of an autostereoscopic systems

In addition to aiding design evaluation and data visualization, an autostereoscopic system has the following advantages.
- No HMD or shutter glass is needed. Some of the display provides real-time 3D views. A variety of formats (video stream or .X, VRML, etc. files) can be supported.
- A much lower installation cost is required than with a CAVE setup.
- The possibility of fatigue is reduced as no glasses are needed.

5. CSCW

Design communication can involve both individuals and teams. One of the factors that affect the efficiency of communication is the quality of media used to represent the design contents. Media varies from photos and digital images, to computer models that are captured or created under different circumstances and stages of design. Before the construction of a design, the communication relies heavily on digital data that can serve different levels of viewing needs in the form of animation or stereographic display. The situation changes when the CSCW contents come from a site that may not exist in finished digital form. In this case, the data must be delivered in a comprehensive manner with a simple setup of devices. This is where an ASD is involved (see Fig. 4). Since design communication usually involves multiple expertise, an HMD type of display is unlikely to be applied without obstruction.

One of the purposes of CSCW is to clarify the ambiguities that can occur in the design process that allows response with the assistance of visualization tools. Formal studies emphasize analysis based on communication model made up of sender, channel, receiver, and feedback. When VR technology is applied during the construction stage, a user can interact with the data more intuitively.

To communicate about a physically presented object, the device setup for CSCW includes a stereo lens attached to a camcorder (see Fig. 5). The wireless video signal is transmitted to a server.
with a receiver attached to a capture card at the back. The video is then viewed through the Internet. The camcorder and stereo lens, which act as a webcam, can be moved around as long as they are within the range of perception and a battery is provided as the AV sender’s power supply. For an ASD, the viewer side needs a corresponding monitor that is ready and switched to autostereoscopic mode. Design work shown from different display method (Synthagram) can also be seen in Fig. 6.

In order to conduct CSCW in ASD, the data of real or virtual subjects feature differently for synchronized or unsynchronized communication. A graphic database has to be categorized accordingly. As shown in Tab. 1, the ASD contents vary as physically presented objects are replaced by computer models. In the meantime, paired images have to be rendered before being posted on web pages. A static ASD effect is made by downloading the images and composing them afterward using the display program provided. For Synthagram, ASD is made by executing a plug-in in 3D Studio for previously created models. An ASD environment is exclusively used for a virtual world. Nevertheless, a closer connection is made with an already familiar modeling process.

Panoramic display in auto-stereoscopic form gives the people on the receiving end an immersive feeling that actually helps to shorten the virtual distance or between sender and receiver. The receiver is aware of the responses of the other parties involved (such as other students or instructors) instead of the responses only of designers and presenters. Whether a panoramic display should be provided for unsynchronized communication remains to be seen. The panoramic view really helps in showing a remote site, especially in an immersive manner.

A test was made to create paired panoramas for auto-stereoscopic display. But the effective region was limited to a fixed orientation. To mimic the eyes’ eccentric viewing of a 360-degree space, paired cameras have to be allocated in the same manner. For a currently available panorama device that is made up of a number of eccentric lenses, the images captured from auto-stereoscopic panorama cameras have to be selected at every other one before being stitched together. This is different from placing a pair of panorama lens attachments and combining two of them side by side.

6. CONSTRUCTION

ASD was used at a construction site (see Fig. 7) with a wireless connection. The distance between sender and receiver was about 50 meters with the former located at the bottom of an excavated third basement floor and the other on the eighth floor of a building nearby. The device setup was rather simple. Signals were transmitted barrier-free while the line of sight was also maintained unblocked for best results. The display clearly showed the steel columns and beams that support retaining walls with visual depth.

Discussion with the project manager showed that the setup was most suitable for a site with potential hazards, as no persons need to be
present, for example at a tunnel excavation. For a site of about 75x72 meters in size and with offices located nearby, works can respond to any site occurrence immediately. The display seems to them less important compared to that of traditional camcorder, unless communication has to be made to the client for a presentation that is more comprehensive.

A construction site is full of complicated activities. Many systems are involved to assist the representation, control, or monitoring of a site with devices such as camcorders, PDAs, or GPSs. The combination of these enables a supervisor to view what is happening at an exact location with immediate video delivery. Now, a GPS can increase the accuracy to about 1 meter. PHS also helps to locate the location of signals. With wide band or high frequency (2.4 GHz) available, immediate video streaming becomes available and accessible all over the site.

The current market only offers a desktop ASD of 15” or 18.1”. An HMD-free display is better placed in an interior with a power supply. The price of an 18.1” HMD-free ASD can reach USD7000. A portable CRT with HMD could be a set of compact displays installed in large quantities to view 3D scenes at a distance from other locations. However, the small size of the screen may prevent it from providing a clear display. Plan for installing an ASD on a tower crane are currently underway. Controlling the lifting or placing of objects with the crane should be more certain with the resulting enhancement of visual depth.

7. APPLICATION PATTERNS AND EXEMPLIFICATION

ASD application in architecture can be seen in many different subjects and fields.

- Visualization of physically presented objects or scenes: in urban and other environments
- Visualization of virtual objects or scenes
  - historical architectural objects: Chinese architecture
  - architectural design
  - hazard prevention
  - building construction: machine operation
- Process inspection
  - tele-operation and autonomous robots for construction
  - control systems for construction machinery (cranes, bulldozers, excavators, etc.)
- computer-integrated building process studies
- construction process modeling and simulation
- monitoring and control of construction processes
- construction work process modeling and automation

8. CONCLUSION

The application of ASD in architectural studies leads to an immersive communication in a small region of display. A corresponding device setup is rather simple, maintenance-free, and low in cost compared to a CAVE-like environment. All components are available on the market. The major task in supporting a study would be the preparation of graphic data for corresponding subjects in a virtual world via renderings or a real world via pictures or videos.
9. REFERENCES


A Management Game for Evaluating the Selection of Project Plans in Construction

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ABSTRACT: Project planning is an essential task of project management that is taught in most undergraduate and postgraduate programmes within universities. However unlike in engineering or other technological areas, students in the management of engineering projects will probably not have the opportunity during their study to test and employ the concepts they have learned about this subject. Project planning is practical subject and previous research illustrates that traditional construction management instruction methods and techniques are insufficient to equip students with skills to solve problems in the real world. There is a belief that management games represent a viable alternative to solving this problem.

This paper describes an experimental management game that allows players to choose their own planning activities to complete a construction project. The game then makes a judgement as to how good the set of activities are.

The work develops theories using tree-like structures to represent project plans. This theory enables a comparison of the players’ plan and a standard plan and a consequent judgement of its goodness. The theory is tested in an experimental computer game. The development and testing of this game are presented and discussed. Conclusions about the feasibility of such a game are presented.

KEYWORDS: Construction, Management Game, Planning, Simulation

1. INTRODUCTION

More and more Universities are offering courses in the area of construction engineering and management (AbouRizk, 1994). Traditionally, the instruction methods used in these student’ curricula rely on exposing the student to applied science courses relevant to the construction industry. These courses and their application to certain deterministic decision models form the basis of the construction engineers training (Sawhney, 1998, Halpin, 1976).

This alone, however, is insufficient to equip students with skill to solve problems encountered in the real world of construction or to convey complex engineering knowledge effectively, see (AbouRizk, 1994). Also curricula often convey knowledge in fragments in a series of courses (Fruchter, 1996).

This means there is a gap in knowledge and experience between the ‘applied science’ graduate engineer and the ‘real world’ construction engineer. Traditional arguments state that experience is the only appropriate basis for filling this gap (Tatum 1987). Therefore it is essential that students get ‘on-the job’ training. This training however is expensive and as (Cullingford et al, 1979) pointed out “it is often impractical to give students access to full-scale projects, where the cost and timescale clearly prelude experimentation”. This leaves the graduate and the employer in a mutually frustrating relationship. Management cannot give important job site problems to the inexperienced graduate to solve due to the high cost of errors involved should he or she be wrong. So important decisions are restricted until years of experience have been gained, consequently the employer bears the cost of the engineers extra education (Halpin, 1976). Furthermore the time for the graduate to fulfil his or her potential is drawn out. This isn’t a positive position for employer or graduate.

In the 1960’s Au and Parti proposed that construction games might be a way of improving traditional methods of teaching, by using “…Computerised heuristic games portraying social, economic, and technological decisions…for the
education of engineers and planners who are engaged in works directly or indirectly related to the construction industry” (Au, 1969).

2. THE DEVELOPED GAME

2.1 Game objectives

The work described here represents a management game that has been developed in order to teach students at the University to use their knowledge and experience to plan activities for a project. The players use the game to test their experiences in the planning of a specific construction project.

In terms of the construction management course, the game is intended to have the following teaching aims:
- To teach activity allocation: what activities are needed to complete the project.
- To teach resource allocation: what resources are needed for a project.
- To teach activity scheduling: activities placed into a network schedule.

The game is still under development and at this stage of the work, only the first aim has been realised.

The game aims on the other hand are:
- To design a game which enables achieving the teaching aims.
- To make the game as realistic as possible.
- To involve an element of risk and luck.
- To make the game graphic.

2.2 Game description

The game is designed to teach students to use their knowledge and experience to plan activities for a project. The players, given the project plans, must consider what activities are needed and to what detail these activities need to be planned to. The game is a ‘model type game’, see Elgood (1989), in the sense that there are standard project models that the game is based on. However it is different in that it doesn’t give the players options to choose from but the player must realise their options. The game is written in Pascal and was developed in the Borland Delphi IDE.

2.3 Game infrastructure

The game, which is tentatively christened as Genesis consists of two parts ‘Editor’ and ‘Player’.

‘Editor’ allows the player to input his or her own project. The game is designed to allow multiple projects to be used as the game’s model. This gives the course convenor, or the students, options over the type and difficulty of projects they might want to practice on. A first year student is not going to be at the same level of experience as a postgraduate; therefore it is important that different types of projects are available.

‘Editor’ also takes the instructor through the steps required to input a project. However the instructor must understand the game before inputting his or her own project because the game requires information about the project structure that can sometimes be difficult to determine.

‘Player’ is the main part of the program. It consists of three major steps as shown in Figure 1. In the first step, the player is introduced to the game; a PowerPoint show gives an overview of the game. It explains the game, its goals, how it is played and what it checks for as well as how it works. If there are multiple projects to choose from, the player can read a project description and load it up. Once loaded, detailed plans of the construction project are displayed in the second step. The player can study these plans, start to plan the activities and input them into the computer. The player can reference all the plans, a project dictionary, a list of their activities at any time, along with the ability to erase, or edit any activities already inputted, save or open activity plans. Stage 2 is completed when the player submits all the activities for evaluation.

![Figure 1. The three stages of the ‘Player’ section of the game](image)

In stage 3, the computer checks and evaluates the activities and plans chosen and the player is given an overall score relative to these checks. The computer also allows the player to view its
evaluation displaying; missing components, false activities, duplicated activities and detail advice.

3. METHODOLOGY

The methodology developed for the evaluation of the plan of work activities is based on theories developed by J. Booth (Booth, 1993). The game has applied some of these theories, developed and adapted them to form a working construction planning game.

The main theory behind this game is the generation of a tree-like structure representing the players plan. This project tree is evaluated using a comparison process against a standard tree. The methodology consists of four stages:
- Standard tree
- Parsing
- Mapping project tree
- Evaluation

These are explained in the following sections.

3.1 Standard tree

Project planning consists of identifying and organising activities. Each activity is a plan of work for a section (or sections) of a project. There are two types of components in an activity.
- Identifiers
- Work Types

An activity is parsed (see section parsing) so that the sentence describing the activity contains only these two types of components. In an activity there is usually only one work type. Multiple work types would suggest multiple activities in one sentence. However there can be multiple identifiers; a typical set of classification categories are:
- Structural Elements (e.g. rafter)
- Structure (e.g. House)
- Section (Area) of structure (e.g. Roof)
- Section (area) identifier (e.g. centre)

Using these components and a set of classifications a tree structure can be created. The components are classified as nodes and the connections between the nodes are classed as branches. In order to structure the tree these classification categories must be prioritised. The priority order depends on what type of orientation the tree should be.

There are many ways of structuring a project tree. There can be a variation in the types of classifications, number of classifications components and the priority ranking of the classification. A tree can be a ‘structured oriented’ or ‘a work oriented’.

To evaluate a players’ plan, the game must compare it to a ‘standard’. A ‘standard project tree’ is used to represent this standard plan. The standard tree represents the limitations of the game; although the player is allowed freedom of choice in choosing the activities there must be a set standard so that reasonable evaluation can take place.

Choosing the orientation, classifications, and prioritisation of a standard tree can be difficult. Different tree orientations may be needed to run different games, no one type of standard tree will be suitable for all the project games. In later developments of this game it is hoped that the ‘Editor’ may be able to choose and select the type of standard tree needed. In this experimental program the editor is restricted to project games that can use the tree structure that the ‘Summer-House Game’, an example project, is based on.

The ‘Summer-House Example Project’ standard tree is a structure-oriented tree with the following classifications and in order of priority:
1. Structure
2. Area of Structure
3. Structural Element
4. Work Type
5. Area Identifier

The structure of the standard tree looks like a tree’s roots, always branching down from stem. This structure is used to demonstrate a detail hierarchy. All the nodes at each level are represented by a ‘rank’ corresponding to its classification priority. This rank gives an indication to the project detail included in an activity. The lowest ranked node in an activity represents all the activity nodes branching down below it.

3.2 Parsing

The game fundamental aim is to give the player the choice over activities he or she plans. In order for this to work the computer must be able to understand the activities entered. The method used for this is a well-known technique called parsing.
Parsing resolves a sentence into its components parts and identifies them.

The game parsing program is used twice; once to identify the sentence and the then to map the component parts onto the standard tree. The process consists of three stages.

The first stage relates to the process of separating the activity into words components. For example the word components for activity ‘Excavate the deck footings’ are:

```
Excavate  The  Deck  Footings
```

The word components must be recognised by the game’s standard dictionary.

The English language presents parsing with several problems: words have more than one meaning; different words can have the same meaning; people often abbreviate words; sometimes two different words can have the same abbreviation. This is coupled with each player having his or her own way of describing areas of the project. To deal with these problems the game has to set some limitations on the words players can use. Every project has its own dictionary of words the ‘Editor’ creates. Nevertheless not just one set of standard activity component names, equivalent names can also be included, e.g. ‘dig’ and ‘excavate’ can be included to mean the same work type. However the dictionary does set a limit on the words the player can use.

There are two types of word included in the dictionary: zero-words and node-words. Zero-words can be defined as having no meaning in the standard tree, but are English word used to construct sentences. Words like: ‘the’, ‘to’, ‘a’, etc. [Note; ‘and’ is not included because ‘and’ suggests the start of a new activity.]; these ‘zero-words’, once identified are dropped from the program. They are not referenced again. The node-words are words that have meaning in the standard tree; ‘dig’, ‘excavate’, ‘erect’, ‘construct’, ‘wall’, ‘walls’, etc

Once the sentence is separated in stage 1, the word components are compared to the dictionary. If a word isn’t recognised by the program as being part of the dictionary, the activity is rejected, the word highlighted, and the player must either reword the sentence using words from the dictionary or exclude that activity.

The third stage of the parsing process relates to assigning standard tree characteristics.

Each word in the dictionary has two identifiers associated with it; Standard word and standard word rank.

Every word has a standard word equivalent, even if it is the same word, and also a rank of the level at which the standard word is in the tree. The parsing stage assigns these identifiers to help the program identify the sentence components in the tree. Zero-words have a rank of zero and are dropped from the program after the third stage.

### 3.3 Mapping the project tree

The game uses the standard tree as a template and maps the project activities onto it. The project tree is evaluated once all activities are mapped on the standard.

The method starts once all the activities have been inputted. The activities are parsed to get the word components and their identifiers. The words are ordered from the highest rank (1 being the highest) to the lowest.

Every activity, in the plan, has an activity number associated with it. Each node in the tree has an activity array. This array contains all activity numbers of which that node is a component. The lowest node in the activity branch is assigned the activity number to its activity array. Once the lowest standard tree node gets the activity number it maps the number down to all, if any, of the nodes below. The other nodes in the branch are not assigned the activity number but they are then tagged as used (this is represented by a node ‘used’ component that is changed from ‘0’ to ‘1’).

Only the lowest node gets the activity number because the other components in the activity are working as identifiers, and may be used in other activities. Although a node activity array can contain more than one activity as shown in Figure 2, ideally they should only contain one. This Figure shows a section, of an example standard tree, where Activity 1 and 2 has been mapped on.
This method, of mapping the activity down from the lowest node, also allows different levels of management. Sometimes the lowest node in an activity could be the highest node in the tree, e.g. ‘Build the Summer-House’, therefore only that activity is needed. Once all activities have been mapped onto the standard tree, the tree is evaluated.

4. EVALUATION OF PLANS

The player’s plan is evaluated based on the following four areas.

Completeness: This is to check that the player has planned the whole project. Once the activities have been mapped onto the standard tree each node is evaluated. Each node’s ‘activity array’ should contain at least one activity number representing that that component is part of an activity. If there is no activity numbers in the array, the nodes ‘used’ array is checked to see if the node has been included in an activity. The reason for this ‘used’ array is because often if a player plans the activities to great detail the node has been used several times as an identifier but because it isn’t the lowest node in an activity it doesn’t get assigned the activity numbers associated with those activities. If a node’s ‘used’ component is not turned to ‘used’ and the activity array contains no activity numbers, the node is classed as an unplanned project component.

Duplication Check: Because the standard tree has a mono-stem structure each leaf node can only be a part of one activity. This particularly useful to check for duplication. The activity array of each node should only contain one activity for no duplication of work. The duplication check views each node’s activity array, if the array contains multiple activities those activity numbers are stored and the player can view those duplicated activities during feedback.

False Activity Check: There are two types of false activities:
- Activities without enough identifiers to identify the branch
- Activities that don’t match any branches in the standard tree.

The mono-stem structure of the tree can result in matching multiple nodes, each part of a different activity. In order to match the activities to their corresponding standard tree branches, each of the activity components must be correctly matched to its standard counterpart. To get a match there must be enough identifiers in the activity (The Summer-House program requires a minimum of two identifiers). If this not the case, e.g. ‘cut East’, the activity is stored as a false activity.

A second check to identify the lowest ranking node in the activity. It then compares it to all the nodes in the tree, once found; it compares the nodes ‘above array’ with the activity’s second lowest ranking node for a match. If there is a match, the second lowest ranking node becomes the lowest node and the process is repeated until the whole activity is matched.

Detail Check: The game allows the ‘editor’ to choose a level of detail the player must plan his or her activities down to. There is a ‘project detail counter’ that keeps track of the level of detail of the activities planned. If at the end of all the planning the counter is less than the editor’s detail level teaching objective. The player pays a penalty and during feedback can find that their plan lacked detail.

The plan is also checked for detail consistency. The ‘project detail counter’ represents the lowest level of detail in the plan. Each activity is then
compared to this lowest level of detail. If the activity can be planned down to this level but is not, the procedure works out how far the lowest node in the activity is from the top and from the detail counter level, or from the lowest level available. This is then fed into an equation to represent a penalty. This method is used because not all activities will be represented in the standard tree down to the same level.

5. TESTING OF THE GAME

The game described in this paper is an experimental program, designed to show the theories described in the methodology are possible. The game has many problems and limitations. To identify these problems the game was tested both technically and for player’s response to the game. Five students have tested the game and their response to design and layout was very positive. Samples of the main points and responses made by the players are:
- Introduction and game instructions were clear and easy to understand.
- Dictionary was very helpful. “There is nothing more frustrating than continually entering something into the computer and it is not recognising it, “the dictionary lets the player see what words they can use”.
- Players were confused by words that could have multiple meanings.
- Players didn’t understand the score. It didn’t carry any meaning or relevance.
- Feedback screen was confusing but once players worked it out, the feedback information was helpful.
- ‘More enjoyable than sitting in lectures because you can have a go in your own time and can learn more by experimenting’.
- “Playing the game is like a problem solving, which is interesting and fun”.

6. CONCLUSIONS

A literature study has shown that there are a variety of past and current construction management games available. Most of these games are based on good ideas and theories but most lack the computer technology of today. Also these games are designed for the player to make decisions from a set of options.

The game described in this paper is an experimental project planning game that aims to make the player realise their own options, input them and get a new resulting situation.

The game uses trees to represent and evaluate planned activities. The methodology behind this is sound, but limited. The method of mapping the trees onto the standard tree can be improved, resulting in a better evaluation of the player’s performance and giving the player more freedom over his or her choices. This generation of trees can also be used in other applications, like resource planning. The game is not a complete program. It demonstrates what a complete game could be, but is not yet ready to be used as a teaching tool.

7. REFERENCES


Primitives Merging For Rapid 3D Modeling

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ABSTRACT: Developing three dimensional models of infrastructure and construction in progress can be useful for designing modifications, for tracking work completed, and for facilitating advanced equipment control and safety functions. An emerging 3D modeling method involves scanning scenes with laser ranging devices. The resulting dense or sparse point clouds are converted to primitive geometric objects. Merging those objects is useful for visualization and advanced manipulation. Factors that influence this merging process are identified here. Heuristics are proposed for automated merging, and initial results presented.

KEYWORDS: RAPID, 3D MODELING, PRIMITIVES, MERGING

1. INTRODUCTION

Methods for modeling the “as-built” condition of facilities and construction in progress have been emerging for several years. Most are based on data acquired using full area scanning laser radars (Ladars). Typical processes involve stochastic based dense point cloud merging, manual identification of volumes of interest, and conversion of point clusters within those volumes to CAD objects that are eventually integrated into a full CAD model of the facility of interest (Stentz, 1998; Stone, 2001; Cyra, 2003).

An alternative approach has been emerging to provide more rapid 3D modeling for construction (Kim, 2000; Cho, 2002 and 2003). Its main characteristics are the use of sparse point clouds, the utilization of the operator’s scene recognition skills, and the division of the environment into target and peripheral objects. While peripheral objects can be roughly modeled by using convex hulls and bounding boxes (McLaughlin, 2003), target objects must be more accurately modeled. For target objects, geometric primitives are used: cuboids, cylinders, spheres, planes, and lines (Feddema, 1997; Kwon, 2003). In many instances of environments, the geometric primitives need to be merged in geometric objects of higher complexity. Therefore, primitive merging methods and algorithms need to be developed.

2. MOTIVATIONS FOR MERGING PRIMITIVES

Motivations for using merging algorithms include:
- Correcting modeling errors
- Visualization
- Improving the richness of models
Modeling Corrections
By saving relationship information between modeled primitives, model corrections can be implemented. For instance, two contiguous pipes in a pipe-spool are very likely to have identical diameters. If the primitives corresponding to the two pipes are very close and present almost identical diameters, they can be adjusted. Similarly, a column and a beam are very likely to be perpendicular to each other. Then, the angle between them can be adjusted if not exactly equating 90°. However, such rules must be used with judgment, since some structured elements deflect significantly and, for instance, some pipes and conduit are not hung horizontally or perfectly in line.

Visualization Improvement
Knowing that some primitives are actually components of a whole can be useful to improve their screen display. For instance, primitives constituting a building structure can be displayed using a different color than those constituting the pipe-spool supported by that structure. The step 1 and 2 in Figure 1 show how that type of information can improve model visualization.

Modeling Improvements
Contrary to the first motivation which is to improve models by correcting primitives, this one aims to model the parts of objects that were not scanned. For instance, elbows are the parts of pipe-spool that are not scanned, so they are not initially modeled. However, since the dimensions of elbows are standardized according to the diameters of the pipes that they connect, it is possible to deduct them from the characteristics of the modeled pipes. As a consequence, models can be improved by connecting all the pipes affiliated to one pipe-spool, like the example illustrated in the step 3 in Figure 1.

Now that the goals of using merging algorithms have been explained, the second part of the paper presents some essentially heuristic methods that are used to reach them, and the initial results obtained with pipe spools.

3. SOLUTIONS FOR IMPLEMENTING PRIMITIVES MERGING

While group affiliation information is gotten by a user’s input during the scanning phase, identifying and processing merging opportunities is an automated process. The heuristics used for this purpose are presented here for the case of pipe-spools.

Specifically, four merging phases that respond to the motivations mentioned previously have been identified. Each phase occurs when its application criteria are met. These criteria are based upon the intensive use of geometrical standards in construction (layout and dimensions), and consist in comparing models to standards and comparing the orientations and dimensions of contiguous primitives to each other. The four merging phases are:

- **Cylinders’ diameters correction:** The method used to efficiently adjust diameters requires a) analyzing diameters of contiguous cylinders and b) comparing the average value to standard values stored in a database. Some fundamental model improvement results from this first phase, and it is necessary for implementing the last merging phase described below.

- **Pipe spool Planarity correction:** Since pipe spools or portions of pipe spools are by nature and design co-planar, this characteristic can be imposed on a group of related pipe sections. A least square method is used to evaluate the optimum average plane from the primary axes of all the pipes constituting a pipe spool. Once this optimum plane is defined, the primary axes are projected on it. Some improvement in pipes orientations result from this process.

- **Cylinders’ orientations correction:** Once pipes are projected on one plane, the angles between contiguous pipes are checked and corrected if necessary. Angles close enough to standard values like 30°, 45°, 60°, or 90° are corrected by rotating the pipes around their centers and within the common plane. Nonetheless, this method is still not optimized because treating angles one by one. A more global approach could be envisaged, in which the total angle adjustments of all pipes would be minimized. But this would be very computationally intensive.

- **Elbows modeling:** The final merging level consists in modeling the parts of pipe spools that are not scanned: elbows. Elbows cannot be characterized as geometric primitives and therefore have not been addressed in the development of methods that model primitives.
from scanned data. However, adjoining pipes characteristics can provide enough information to derive the elbows. Since all the parameters necessary to model an elbow are standard and based on pipes diameters, they can be deducted as soon as the closest standard diameter of the contiguous pipes has been determined. Thus, the elbow can be positioned and the lengths of the connected pipes recalculated in order to completely reconstitute this section of pipe-spool.

4. FIRST EXPERIMENTAL RESULTS

The presented phases have been coded and tested within the MATLAB software environment. An example of experimental results is provided in Figure 2. Although the figure displays a very simple case of pipe spool, it must be noticed that, once the pipes are scanned (the small cylinder sections on the figure), the code only takes a couple of seconds to generate the final model (the long cylinders). This model doesn’t display the elbows since generating elbows in a MATLAB environment requires tedious programming. Nonetheless, their dimensions and positions are provided by the code, and a more convenient interface is currently under development.

5. CONCLUSIONS AND RECOMMENDATIONS

The approach to merging primitives introduced in this paper show potential for improving 3D models in key ways. It can be used to correct errors generated during the primitive modeling phase, but also to deduce complementary information to improve the quality and precision of models.

However, although the principle of using merging methods is validated, its implementation is far from completion. Some encouraging results were obtained. Significant computational model improvements can be made at a low cost. But, the algorithms still need to be improved and tests performed.

6. REFERENCES


[Cyra] Cyra Technologies, Inc. 8000 Capwell Drive, Oakland, CA 94621, Tel: (510) 633-5009, www.cyra.com., 2003


Step 1: No Primitive Merging Process

Step 2: Only Primitive Affiliation Process

Step 3: Complete Primitive Merging Process

Original Scanned Environment

Figure 1: Example justifying the use of merging processes in environment modeling

Figure 2: Experimental Results of the Merging Method
Implementation Scenarios for 4D CAD in Practice

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ABSTRACT: The application of 3D and 4D CAD software is considered to be able to offer possibilities for more consistent project documentation and visualisation, which should eventually enable fail cost reduction. 4D software is seen as a tool for project organisers and project team members to better communicate and analyse schedule information. In this paper experiences with 4D CAD software in construction projects are discussed. Analyses of these experiences and additional user experiments have lead to a short-term and a long-term implementation strategy in practice.

KEYWORDS: 4D CAD, construction, simulation.

1. INTRODUCTION

Caused by the increasing complexity of construction projects, concurrent scheduling of building construction activities as well as insufficient project insight can result in inadequate schedules, which can induce problems during construction of a project, resulting in delays throughout the construction phase. Besides that, parties, involved in projects, communicate in a way that is far from the most effective. Communication conflicts result in misunderstandings about responsibilities between parties, which can, subsequently, cause problems during construction.

The two distinguished problems concern project information analysis on the one hand and project information communication on the other hand. 4D software is thought to be able to support creation, analysis and communication of schedule information [Fischer, Kähkonen]. Therefore, application of 4D software might be a remedy for these issues; the research aimed to investigate the added value and shortcomings of application of 4D software at HBG, a construction company in the Netherlands.

2. 4D CAD

4D software supports linking of 3D (CAD) geometry to one or more schedule activities, as reflected in Figure-1. The result of an established link of 3D geometry representing building elements and schedule activities, is a simulation of the planned building process. The simulation enables analysis and communication of a schedule, as created by a project organiser.

Figure 1: General description of 4D software functionality

During the research, “Invizn”, 4D software of Stanford University’s Center for Integrated Software Engineering (CIFE), was used. The software features a VRML environment in which instances of 3D CAD geometry can be linked to schedule activities using 4D components. 4D components are defined in a user breakdown structure of the 3D model. Breaking down the 3D model following the construction breakdown as
defined in the schedule, enables groupwise linking of schedule activities to the 4D components. By defining activity types with a unique colour coding and consequently assigning them to schedule tasks, construction schedule activities are made recognisable, since the 3D geometry appears in the construction type colour when it is put in place.

3. PARTICIPATORY RESEARCH

Participating in a 3D/4D modelling process seemed to be the best way to discover benefits and problems in the use of 4D software. Two projects were used for this objective, namely a shipping centre in Rotterdam and a World Trade Centre in Amsterdam.

1st application: Shipping centre Rotterdam

During the project, extensive collaboration with the project organiser formed the basis for the creation of the first HBG 4D model. Tasks, that have been carried out in this collaborative 4D model creation consisted of: 3D modelling, scheduling, and 4D modelling. An important aspect of 3D modelling was how the 3D CAD model should be set up to “fit” to the schedule’s breakdown. Vertical and horizontal divisions of the building model had to follow the construction order of the project. 3D modelling was finalised by exporting the model to a VRML format. Using AutoCAD, this required several steps. The actual 4D modelling – dragging and dropping 3D components and schedule activities into 4D components – was carried out by the project organiser.

In advance of the project start, there was a kick-off meeting, to explain the designed construction method to the foremen involved. During this meeting, the 4D simulation was shown to the attendees. In order to get reactions about the application of 4D software on “their” project, the auditors were asked to fill out a questionnaire. In this questionnaire they had to express the three most important construction issues in the project. The questionnaire had to be filled out twice: before and after seeing the 4D simulation. The results of the questionnaire differed. Some people gave exactly the same answers before and after, but other people came up with other aspects of the construction process after they had seen the simulation.

The auditors were encouraged to give their opinion about the use of a 4D model in a discussion after the presentation of the simulation. During this discussion it became clear that most of those present were enthusiastic about the 4D model; some of them even had a wish for additive information in the model, e.g. to analyse security aspects of the construction process.

The use of 4D software in the Shipping centre project clearly indicated what constraints play a role in 4D modelling with regard to 3D modelling and schedule set-up. Also, the issue of naming of 3D and 4D components as well as schedule activities arose.

2nd application: World Trade Centre Amsterdam

The main attention of this project went out to the construction of the tower. The concrete core of the tower is constructed using hydraulic, self-climbing formwork. The construction of the core must have a lead of about 3 to 4 climbs on the construction of the slabs. This margin is needed to get enough space for the climbing process of the self-climbing formwork (space required for the hanging scaffold).

A rough schedule for the construction cycle was already made. The number of cranes that were needed for one climb was calculated using this rough schedule. A detailed schedule had still to be made.

Because movement of temporary construction elements isn’t supported by the 4D tool, it had to be simulated using a “appear – disappear” mechanism. This way of visualising movement requires a 3D representation of the equipment in every occurring situation (see Figure-2), resulting
in large VRML files. Another requirement for the simulation of moving equipment is the introduction of activities that control the appearance and disappearance of the representation. This leads to an increased amount of activities in the project schedule, which, again, complicates the use of the schedule in the 4D tool. While creating the schedule for the construction cycles of the WTC project, a problem with the planning units was encountered. A construction cycle is set up using workdays and not calendar days; however, the time basis for the 4D tool is a calendar scale. The planning unit for detailed schedules (like a cycle planning) is often smaller than the smallest unit of the 4D tool, namely a day.

**Hands On Session**

In order to give HBG employees, involved in project management, a first impression of the functionality and benefits of 4D software, a “Hands On session” was organised. In this session, the attendees were informed about 4D research, the pilot project Shipping centre and expected future developments. To give the participants a “4D experience”, a number of exercises were arranged.

The most important exercise was bifold: firstly, participants had to analyse a construction planning using only a bar chart and a set of drawings. Secondly, they could analyse the same project planning (with other errors in it) again, now facilitated with the 4D CAD system.

The result of this exercise proved the possible benefit of use of 4D software: the support of 4D CAD improved the quality of the analysis within the given time of 10 minutes. People got more motivated to answer the questions (more answers) and were able to do that quicker and more accurately (more correctly answered questions).

### 4. 3D/4D MODELLING PROCESS

Experience in 4D software use was gained during participation in the research projects. This resulted in a description of “best practices” for 3D modelling and scheduling.

**3D modelling**

Essential in the creation of a 4D model is the 3D modelling part. Based on the experiences, a flow chart has been set up (see Figure-3).

The modelling method is mainly determined by the answers on the questions (represented by spades in the flowchart):

1. Existing 3D model available?
2. Existing 3D model usable?
3. ADT model or “Traditional” 3D CAD model?

4. The first thing to do when there is a request for the creation of a 4D model for a project, is to contact involved parties to check whether there has already been made a 3D model of the project. Any available 3D information can support the 3D modelling process; even coarse .DXF wireframe models can give a good impression of dimensions and geometry.

5. At some moment, a decision must be made to either use the existing model or to start a new model from scratch. 3D models made by visualisation companies can be highly detailed, which isn’t suitable for most 4D use purposes because it mostly unnecessarily slows down the eventual simulation.

6. Possibly available 3D models can be derived from several drafting and analysis software. Because Architectural Destktop (ADT) from Autodesk™ is the standard drafting software within HBG, the ideal situation is when the existing model is created in ADT. In that case, the model can be adjusted and fine-tuned with the use of (specific HBG) ADT components and work methods. “Traditional” 3D CAD models (“wireframe” models) can also be used, but are more difficult to handle.

**Scheduling**

At the moment, scheduling and modelling, as well as scheduling and cost estimating are completely separate activities. Therefore, the “products” of these activities aren’t geared to each other. The result of this “island”-like work method is that when 4D models have to be created, all the work concerning gearing the 3D model to the schedule is still to be done. With respect to this, consulting the project organiser in advance of the 3D modelling work is a way to prevent repeatedly rework.

### 5. WORK METHOD QUADRANT

Application of 4D software is not part of day-to-day practice. UML use case scenarios and diagrams are used to describe current work method, current 4D supported work method and ideal 4D supported work method. Because its implementation causes changes in work methods, the SAP (HBG’s financial and managing software) work method is also part of UML models.
Placing the work methods in a quadrant (Figure-4) enables comparison of the UML models, which gives a view of required adjustments and additions in work method and software.

![Figure 4: Variances between UML defined work methods](image)

The work method in current project organising practice has been analysed in the first phase of the research; interviews with project organisers were held to clear up the current work method. SAP software brings about a business-oriented approach of project organising. The set up of a Work Breakdown Structure (WBS) is most important in the application of SAP for planning purposes.

The UML schemas in “current practice, using 4D software support” section give a description of current practice, based on results of interviews with project organisers and own experiences during participating research.

The work method for the use of 4D software as an extension on current practice features two main processes: creating a schedule and creating a 4D model. Important complaint on this work method is that the created 3D and/or 4D model can only be used after finishing it completely. Since 3D and/or 4D models can also be beneficial for project analysis in an early stage of a project, more integrated processes are desirable. This is reflected in the “desired work method”.

6. IMPLEMENTATION SCENARIOS

The “desired” work method requires a reconstruction of the currently applied work method(s). Based on the UML schemas, two applicable transition scenarios are thinkable. These transition scenarios, reflected in Figure-5, implicate a long-term scenario and a short-term scenario.

![Figure 5: Transition scenarios: blue=long-term; yellow=short-term](image)

The short-term scenario is mainly based on currently available software tools that play a role in the project organising and 3D/4D modelling process. Adding functionality and upgrading to database and integrated environment technologies reaches the eventual goal. Because the start of the short-term scenario can be at a short notice, it is most suitable for a quick distribution of the 4D software. Consequently, adoption of 4D software as a new tool for project organisers and managers is feasible in the short-term scenario. However, full integration is not possible because the applications will be developed separately.

A development strategy, based on SAP standards, will be a long-term scenario. In this scenario, data produced by the schedule application and ADT is stored in a SAP WBS. Schedules are made using SAP functionality. Upgrading the 4D software to database technology and linking it to the enterprise system (SAP) will result in a fully integrated environment. Additional data (resources, cost/budget and risk) can then be stored in the WBS part of concern. The link between ADT and the SAP WBS will be established by software, which enables conversion of ADT geometry to database records.

The best applicable next step to take will be to work out the currently feasible solutions, listed below.

- Simplified 3D CAD to VRML conversion – realised during the research;
- Naming convention, which ensures compatibility throughout the 2D/3D/4D modelling process of all model parts;
- Improved import and export functionality for schedules to ease the update of both 4D model and schedules;
- Easy to use 3D sketch tool to enable fast creation of 3D models.

Particularly the naming convention is essential for further development and utilisation of the 4D supported work method. Naming is in itself closely related to classification, which is an ongoing research theme.

7. CONCLUSIONS

The proposed development of the software will only be effective when a more cooperative and integrated work method is introduced. A new approach, indicated by the HBG wide implementation of SAP software, might form a basis for the new work method [Broekmaat].

The way projects are organised greatly influences the opportunities for effectuation of (applicable) cooperative and integrated work methods. In this context, “design and build” organisation types seem most valuable.

8. REFERENCES


Start 3D/4D modelling process

Existing 3D model available?

Yes

Analyse existing model

No

Consult project organiser

Existing 3D model usable?

Yes

Consult project organiser

No

Set up ADT model

"Traditional" 3D CAD model

ADT model

Edit/group/add AEC objects to gear 3D model to schedule

ADT model

Add relevant equipment

The ADT model to be set up should follow the project breakdown structure of the project organiser.

"Traditional" 3D CAD model

Edit/group/add plain 3D geometry to gear 3D model to schedule

plain 3D model

3D model (.DWG) of project

Figure - 3: flowchart of project 3D/4D modelling
Towards a Comprehensive Feasibility Analysis for the Use of Robots in the Construction Industry

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ABSTRACT: Feasibility studies must cover different disciplines such as need-based feasibility, technological feasibility and economical feasibility. In the present work a comprehensive feasibility analysis model for the use of robots in performing construction tasks is presented. This model is mainly focussed on the need analysis in order to present criteria for decision making. The decision making is performed using the (give in full?)AHP process as a judgement tool for multiple criteria decision-making problems. Four criteria are developed for the decision-making process based on the parties involved in the construction process such as labour criteria, process criteria, site criteria, and management criteria. Safety risk assessment tools are used to emphasize the motivation for task automation from the safety point of view. Simulation tools and existing robot prototypes are used to demonstrate solutions for resolving the safety and technical problems involved in the elected tasks, and to identify the required level of automation. A case study is presented based on the use of the Starlifter robot in heavy tool deployment such as diamond core drilling and plunge sawing in hazardous environments.

KEYWORDS: Robots, Automation, Feasibility analysis, The AHP Process, Safety, Risk Assessment, and Simulation

1. INTRODUCTION

The automation of construction processes can be considered at different levels namely:
• area level such as general concrete work,
• activities level such as rebar fabrication
• or task level such as bending, positioning and tying tasks.

Breaking down the construction process this way makes the automation process easier [Gue]. The automation at task level is more feasible than higher levels, because the higher levels include multiple tasks, which makes the automation process more complex and difficult to control.

The potential for construction task automation needs to be justified from different perspectives. The first perspective is the need for automation, the second is what level of automation is desirable and the third is economic feasibility.

Kangari and Halpin identified a range of factors affecting the use of robots in construction. These factors are divided into three groups, need-based feasibility, technological feasibility and economic feasibility, which are similar to the above-mentioned perspectives. [Kangari] These groups are used in the overall feasibility analysis. Which adopted a fuzzy logic model for the evaluation of the decision to use robots. Kangari suggested that economic benefits, improved production and quality must pay-off the cost of development and marketing of the automated process and that it should not depend only on safety arguments.

Gue and Tucker presented a systematic framework for evaluating the potential of automation of generic tasks using an automation concern index, ACI, which is based on the AHP process. [Gue] Hastak, developed a conceptual decision support system for the use of robotic systems in construction activities. [Hastak94] This system is based on AHP and the criteria of judgements are need-based criteria, technical criteria, economic criteria and safety and risk criteria. Hastak applied the same methodology to a pipe laying process. [Hsatak98] The data used for this study was based on interviews with experts in the field of pipe laying. The results of this study showed a preference for the use of automated pipe laying equipment over conventional open cut trench methods.

In the above-mentioned studies, the decision to use automated processes assumes the availability of the required technology on which a complete feasibility study can be performed. In the broader case of choosing which new tasks can be automated and what levels of automation can be achieved we need to modify the steps of the decision-making process.
Many barriers come in front of the final implementation of a robotic system in the construction industry. The identification of these barriers is of great importance because it greatly influences the final decision to use a robotic system. It needs emphasizing that the identified barriers, technological or economical, must not affect the need feasibility. I.e. The need feasibility must be done on the basis that the elected task for automation is identified based on safety risk and productivity related factors. This allows a structured feasibility analysis.

In the present work a comprehensive feasibility analysis model is presented in a structured way to enable a comprehensive need analysis which is followed by a decision making process based on the factors identified in the need analysis part. The identified barriers can then be analysed and resolved according to their category, i.e. technological or economical, to move forward to the final implementation.

2. FEASIBILITY ANALYSIS MODEL

For any construction task it is not easy to judge the immediate benefits of using new technology unless a complete analysis and evaluation are performed to define the needs and benefits. The present model provides tools for the analysis and defining the benefits of using automated processes through a systematic way. One of the main objectives of this feasibility analysis is to examine the possibility of using one robotic system for multiple tasks with different characteristics. In other words to develop a flexible robotic system that can be configured to perform different jobs i.e. a general purpose robotic system. This analysis could lead eventually to the economically feasible use of such robots. This approach can be applied to a wide range of tasks and jobs that share similar characteristics.

In the present project several case studies are considered in order to examine the feasibility of using the Starlifter robot, [Zied]. These applications cover situations that encompass both safety and technical capability problems.

2.1 Model description

In the present work, an integrated systematic model is developed to help the decision maker to analyse, evaluate and decide the implementation of new robotic technology. The feasibility analysis model basically consists of four stages namely; need analysis, decision-making, technology approval and economic analysis.

In the need analysis stage, comprehensive analyses are made to identify the task characteristics and the level or levels of automation the automated task is going to use. The outputs of this stage are: firstly alternatives for performing the task (this could include the recommendation to use a refined version of conventional methods of carrying out the task, or even to use the conventional methods as they are). Secondly, selection criteria for the decision making stage for each alternative. These criteria are based on risk analysis and identification of operational characteristics.

The alternatives and their selection criteria are together passed to the decision making process which uses methods such as AHP Interview-based questionnaires are made with experts or other related people in the field. This approach is usually employed when using the AHP process [Saaty]. The alternatives and criteria should be strictly defined for particular cases and not be generic. The experts in the field should be knowledgeable concerning conventional methods, however, in addition, they should be aware of new technology. Some form of demonstration of the new technology is required to get reliable information. This could be done using existing production versions of the technology, working prototypes or at minimum, reliable simulations of the technology if it is still under development.

The outcome from the decision making process supports the use of one of the alternatives, which could be the traditional methods, however if the decision-making process suggests the use of automation, further analysis needs to be done. For the elected level of automation a technology approval procedure will be employed to identify the details in terms of the robotics system requirements in order to satisfy the working conditions specified in the need analysis process. The robotic system
requirements for a certain level include five modules identified by Esposito et al:

- locomotion,
- robotic platform,
- sensors,
- controller
- and endeffector. [Esposito]

These five modules vary for each level of automation. For example for the basic level of automation; the modules could be reduced to a manipulator, a teleoperation controller and a simple grasping endeffector. For a higher level of automation a mobile platform could be integrated to do the locomotion function with a sensor guided controller and automatic tool changer endeffector.

2.2 Methodology

The task analysis part describes the characteristics of the task using traditional methods. The task characteristics can be obtained using the standard rules of task execution, the code of practice or from field experts etc. A knowledge acquisition technique can be employed to collect all the required information about the task under automation. The task characteristics can be identified in terms of:

- Working Environment
- Links to other processes
- Process duration and frequency
- Current operational techniques
- Worker numbers and level of skill
- Tools and supporting equipment

3. ENVIRONMENT VARIABLES AND ROBOTIC AUTOMATION

The task analysis process defines the characteristics of the task and its surroundings. In other words the characteristics of the environment (the system) under study. As described by Hathaway, a system is composed of many interacting sub systems -See Figure (2). [Hathaway] These subsystems are procedures, support equipment, people, software, hardware systems, facilities, operating environment and other interfaces. The subsystems are linked and interacted together in the overall natural environment.

In a survey reported by the North West Development Agency about the potential benefits of automation in construction, based on interviews with experts in the construction industry in the area, reveals the following benefits: [Thomas]

Figure (1) the feasibility analysis model

Figure (2) the environment variables when using traditional methods [Hathaway]
• Improved working conditions
• Improved health and safety
• Simplified operations
• Improved productivity
• Competence in the face of a shortage of workforce and skills

The above benefits can be simplified to two primary Firstly safety and secondly improvement in operational characteristics.

From the safety point of view it is desirable to reduce the amount of the interaction and the link between people and the operating environment. Figure (2) shows the direct interaction of humans with the operating environment and other subsystems such as hardware systems; while in Figure (3) human interaction is limited to the interaction with software and procedures such as operation instructions and safety precautions. The degree of interaction with the hardware subsystem depends mainly on the level of automation the process under consideration. The level of automation needs to be linked to the level of hazards involved in the system, consequently it is essential to perform a hazards analysis to determine the safety risk level.

A. People (labour)

Labour are an essential part of the system when performing tasks using traditional methods. The nature of task characteristics could lead to the following problems, which could be solved by using robotic automation:

A.1 The task requires highly skilled labour, which results in high cost and longer operating times. The reasoning behind this is high wages and declining skilled workforce.

A.2 The task is tedious and boring, for example the worker has to hold a heavy tool in an inconvenient position repeatedly.

A.3 The task requires multiple tools. The task requires high precision and accurate positioning of tools.

B. Procedures

Procedures are the steps the worker should follow during task performance. This can be explained in the following points for a core-drilling process as an example:

B.1 working area marked
B.2 tools adjustment; positioning and rate of feed.
B.3 testing the working area for reinforcement if it is required to avoid drilling through it.
B.4 planning the working area in the case where more than one worker is doing the same task at the same time.
B.5 procedures that should be followed in case of an emergency such as a tool jam, injuries or accidents.

It is essential to identify these procedures and analyse the situation when a robotic system is employed to determine how far the use of a robotic system can modify these procedures.

C. Hardware systems

Hardware systems include any tools or rigs that are used in the task performance. Some organizations have a technology strategy to consciously develop and implement new tools and logistics to improve the performance of traditional methods. Examples of this are changing from manual feed to automatic feed of the core drilling process, which results in accurate cutting and safe operation, and the use of less noisy and vibration free equipment.

D. Support equipment

Supporting equipment such as power generators, water sources and air compressors are needed for both traditional methods and automated processes. Modifications can integrate this equipment into one
platform to support the robotic system and make the control process more efficient and easy.

E. Facilities
In construction sites facilities like site access, scaffolding and material handling are required before starting any construction tasks. In some situations it is necessary to scaffold the entire working area to enable workers to perform the task easily and safely. This adds extra cost, which can be eliminated or reduced by using a robotic platform capable of performing the in areas with difficult access.

F. Software
Operators are increasingly comfortable interacting with software rather than hardware systems. Robotic automation is mainly characterised by software. Designing the software with user-friendly interfaces is vital to enable the operator to control the system efficiently and providing feedback from sensors, etc is essential for safe operation.

4. THE DECISION MAKING PROCESS
The basic idea of AHP is to decompose a complex system into a structured hierarchy in order to identify the elements or criteria that control the problem. Simple pairwise comparisons are then made between criteria, sub-criteria and alternatives to provide priorities at each level, which finally contributes to the final decision.

4.1 Preliminary Control of the Decision Problem
A hazard analysis process defines the system characteristics and the hazard risk categories. It is necessary to control the decision making process by eliminating non-relevant criteria. A primary list of criteria and sub-criteria can be prepared according to the factors discussed by Kangary and Halpin. [Kangari]. This list can be modified to suit the system under study. A questionnaire can be prepared for the task under study describing the system characteristics when using traditional methods.

4.2 Criteria for the Need Analysis
Decision-making models were employed to validate the use of automation in construction. Most of these models utilised the opinions of experts in the field. From the literature, need-based feasibility; technological feasibility and economic feasibility are used as the main criteria for decision-making. The decision-making process is based on the fact that the automated process is already existing and developed to a stage that the economic and technological feasibilities can be investigated. For the purpose of decision-making in connection with the development of robotic systems for multifaceted construction process, it is necessary to construct a hierarchy for the problem. In the present work four criteria are used which represent the elements of the construction process, namely, labour, process, working environment, and management. Some of the sub-criteria are previously identified by Kangary and Haplin. Figure (4) shows the complete hierarchy of the decision problem of the automation of concrete sawing and core drilling processes as examples of multifaceted processes. The following is a list of the main criteria and sub-criteria:

- Labour-wise criteria
- Process-wise criteria
- Working Environment-wise criteria
- Management-wise criteria

5. CASE STUDIES
Case 1: Innovation of a lead contaminated building [CSDA]
Renovation is required of a building formerly used for storage by a battery manufacturing company. It is required to remodel an antiquated plumbing system, enhance the look of the building and open it up to provide more natural light into the work area and provide easier access for people and products. The work includes cutting and removing the concrete floors with openings varying from 450 mm to 1.5 metres, the floor thickness varying from 150 to 200 mm.
A total of 2000 lineal metres of floor contain 407 tones of concrete. Wall sawing is required to open 37 new windows and doors ranging from normal size to openings of 3 m × 8 m i.e. a total of 200 metres of wall sawing to remove 250 tones of concrete. The building can be considered as a hazardous environment as it is contaminated with lead. It is necessary for all workers to pass a battery of blood tests and to wear disposable hazard suits. The equipment used in the traditional process are cushion cut hydraulic wall saws, Target 35 HP saws equipped with clean air catalytic converters, skid steer vehicles and fork-lift trucks.

**Case II: Drilling holes for power cable brackets inside a rail tunnel.** [Reihl]

It is required to drill holes through a rail tunnel wall for fixing power cable brackets. The work volume: core drilling is performed to provide four holes per one cable holder for a total of 1000 holders for a tunnel length of 3 km. Work to continue without closing of the tunnel, i.e. the drilling tasks are performed while trains are moving on the other track. The equipment used: diamond core drills on SRS rail track trucks as a platform for the supporting equipment.

**Case III Anti rust cathode inserts,** [Zied]

The case study is based around a real contract that was completed, using traditional methods, in Southern England in 1998. The main task consists of the drilling of 1000 holes 300-400 mm in depth in the underside of a major motorway bridge for the purpose of inserting cathodic protection rods, in order to reduce corrosion of the reinforcement bars. The task must avoid drilling through existing reinforcement bars.

For these three case studies, hazard and job characteristics are identified according to the subsystems involved for each case. Simulations of the proposed robotic systems to perform the involved tasks are prepared for illustration purposes in the first place to appraise the robotic solution. The same problem hierarchy illustrated in Figure (4) is used for all the case studies however in some cases it is useful to eliminate the non-relevant sub-criteria to reduce the calculation volume of the priority vectors.

**6. RESULTS AND DISCUSSION**

The decision making process was performed using the EC2000 software [EC2000]. The EC2000 software is basically based on the principles of the AHP process developed by Saaty. For each case the priority vectors are estimated for the two alternatives, robotic automation and traditional methods. The input data are based on the personal judgement; however sensitivity analysis is applied to show the variation of the final decision with different judgements. For the three cases, the decision favours the use of robotic automation because all of these cases involve safety and
technical difficulties when using the traditional methods. For case I, the decision is in favour of robotic automation with 67.1%. Figure (5) shows the percentage contribution of each criteria and sub-criteria. The labour and process criteria show significant effects in influencing the preference for a robotic solution. Robotic systems are assumed to reduce or eliminate hazards by reducing direct contact of labour with the working area. Also removing humans from the loop can increase productivity and reduce delay in task performance due to the elimination of tedious and boring tasks. This conclusion can be withdrawn when we look at the nature of the environment in which hazardous environment contributes by 4.7% of the total preference or robotic automation. For case II the preference of robotic automation is 61.84% which should be set against the technical problems involved in this case study when using robotic automation. For case III, preference is 60.8% in favour of the robotic automation which is compromised by economic factors that result from a less hazardous environment with fewer technical difficulties.

7. CONCLUSIONS

The present model provides a comprehensive (Only part of the analysis?) analysis for the use of robots in construction industry. The need analysis part provides important information for the system developer as well as the decision makers in which detailed analysis of the task under automation from different points of view can be performed. The use of AHP in the decision making provides immediate decisions according to the entered judgements. The hierarchy of the problem is flexible, whereby different criteria and sub-criteria can be introduced to consider different aspects of the task under automation. The technology approval part of the feasibility model is needed to solve the technical problems raised during the need analysis. The economic feasibility is the driving force for the final implementation of a robotic system once the need and technology approval analyses are fulfilled.

8. REFERENCES

[CSDA], 1999,“Hazardous materials, contamination exercise special precautions”. Concrete Openings, V8 No.3 Specifiers, Concrete cutting resource guide, CSDA.


[Reihl], 2001, Construction Robotics Ltd, Rail tunnels contracts files.


Criteria For Selection of Software Development Environment
For Construction Robotic Systems

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ABSTRACT: The selection process for a suitable programming environment for construction robotic systems should satisfy a range of requirements identified from both a users and systems point of view. In the present work two different object-oriented programming environments are chosen for comparison, namely MATLAB as an example of text-based programming and LabVIEW as iconic-based programming. The selection of the appropriate development environment is performed using the AHP process for decision-making. Several criteria and sub-criteria are identified and used for the selection process. A complete hierarchy of the problem is constructed and priority vectors are identified. Sensitivity analysis on the results is performed to identify the factors affecting the final decision. For the entered values of the priority vectors, the obtained result shows a preference for LabVIEW over MATLAB as a software development environment for construction robotic systems.

KEYWORDS: Robotics, Software, AHP, Decision-making

1. INTRODUCTION

The development of robotic systems in construction advances very slowly owing to several challenges, [Garas]. One of the obstacles is the development of the required software components. This is a major obstacle because of the requirement for highly trained programmers and expert software engineers. Software represents a substantial part of the overall complexity of a robotic system. In most development systems, software is the component on the critical path and is usually blamed for system development problems, [Stevens].

In a robotic system, software plays a vital role in many sub-systems, including the controller, sensors and user interfaces [Seward & Zied]. Hence a robotic system can be considered as computer-based system CBS. A CBS is a mixture of software, hardware and people but the software is considered as the core of the system and the key element for cost, added value and risk [Thome]. The need to apply Systems Engineering principles is clear because the design of software needs decomposition, risk management, interface control and integration, which are the elements of Systems Engineering as described by [Stevens] and [Martin].

The software development process requires a powerful programming environment that can produce functional and reliable software to satisfy the end user needs, as well as the developers’ needs. The characteristics of a robotic system oblige us to select a powerful software development environment that enables modularity, easy integration and reusability. For example, in the present project, the Starlifter robot –See Figure (1) [Zied 2001], the robot controller, ATC is working on Windows 3.1 operating systems which uses 16-bit data format, the operating software for the RotoScan, laser scanner for range measurements [Seward 2002] is a DOS based program etc. This illustrates one of the difficulties involved in integrating these components of software into one user interface The need for a programming environment capable of dealing with these problems is obvious. This environment must allow modular design and easy interfacing with other software written in different programming languages etc. Another problem arises from the fact that these systems are invariably one-offs or low volume products, and so the resources that can be invested in software are severely limited. Object oriented programming environments fit the above requirements; it is however difficult to start from scratch in the software development process which implies the need for ready-made components that reduce the development time and cost.
In the present work two software development environments are considered for comparison, MATLAB which is a text-based programming environment (TPE) and LabVIEW which is an iconic-based programming environment or graphical programming environment (GPE). Capabilities of both environments are examined to reach a final decision as to which one is appropriate for the development of software for construction robots.

2. THE SELECTION PROCESS OF SOFTWARE DEVELOPMENT ENVIRONMENT

Most researchers choose a software development environment according to their personal preference and the skills they already have in programming. Current personal skills and the availability of the development environment affect the decision of whether or not to use a certain development environment. For example people familiar with MATLAB or VC++ tend to choose them in the first place regardless of the capabilities of the environments and the development time that these environments will consume.

From the authors’ personal experience, firstly, it was decided to use MATLAB as the software development environment because of past experience in programming. However, after spending some time MATLAB programming it was found that excessive programming resources would be required to complete the system. VC++ was tried for creating user interfaces but it was found difficult and time consuming. Eventually it was decided to use LabVIEW because of the availability of the hardware that required interfacing with the robot.

In the following section, selection criteria are presented to enable developers to choose the right software development environment from different points of view. The selection process is based on the AHP process [Saaty].

The starting point of the selection process is to make a hierarchy of the problem showing the goal of the problem and the alternatives.

2.1 The Problem Hierarchy

Whitley and Blackwell [Whitley] presented a comprehensive survey-based study on visual programming versus textual programming. In this study they compared two types of languages, textual and iconic. This comparison is based on surveys between programmers who use these two types of languages. It is important to identify that they used the term visual programming to represent iconic programming, which in the present study is referred to as Graphical Programming. The results of these surveys showed that there is a great difference in opinion between academics and professionals regarding the capabilities of programming languages in general. “Researchers have ambitious theories regarding the influence that new programming languages can exert on mental processes of the programmers” Professional programmers are mainly concerned with productivity, which is represented by reusability, and they prefer their existing tools.

Graphical Programming users admitted that the visual representation of functions is more advantageous than re-usability in LabVIEW.

[Whitely] presented several criteria, to compare textual and graphical programming. These criteria are regrouped in the present work into four main criteria. These criteria in addition to other criteria related to personal experience are used to select a software development environment. The main criteria are:

1. General criteria
2. Technical (Beginners) criteria
3. Technical (Advanced) criteria
4. Practical criteria

Figure (2) shows the hierarchy of the problem, the first level is the objective or the goal, which is the selection of a software development environment. The second level is the selection criteria and the third level is the alternatives, which in the present study are, LabVIEW and MATLAB.

2.2 Priorities Setting

The AHP process consists of two main steps; the first step is the pairwise comparison between criteria at the same level i.e. comparing the relative importance between the main criteria in the A-level and between the sub-criteria in each main criteria. The second step is comparing the preference of one alternative over the other relative to the individual sub-criterion.

In the present work all of the data supplied to the process are based on the authors personal judgement and past experience. The process analysis is performed using Expert Choice 2000 software (EC2000). EC2000 is based on the principles of the AHP process developed by [Saaty]. The data obtained is verified manually to confirm the correctness of the output data. The following section illustrates examples of the output from the AHP process:
Figure (2) The selection problem hierarchy

Figure (3) Percentage contribution of sub-criteria for MATLAB (M) and LabVIEW (LV) at different levels of the hierarchy in the decision process
2.2.1 Level A: Main criteria
Compare the relative importance between the main criteria

\[
\begin{array}{cccc}
A_1 & A_2 & A_3 & A_4 \\
\hline
\text{General} & 1 & 1/5 & 1/5 & 1/2 \\
\text{Technical} & 5 & 1 & 1/2 & 2 \\
\text{Beginners} & 5 & 2 & 1 & 1 \\
\text{Technical} & 2 & 1/2 & 1 & 1 \\
\text{Practical} & & & & \\
\end{array}
\]

Weight Vector

\[
\begin{array}{c}
\text{Inconsistency} 0.08
\end{array}
\]

2.2.2 Level B: Sub-criteria
Compare the importance between the sub criteria relative to A1 = General criteria

\[
\begin{array}{ccccc}
B1.1 & B1.2 & B1.3 & \text{PV} & \text{WV}
\end{array}
\]

Impact \( B1.1 \)

\[
\begin{array}{ccc}
1 & 1/5 & 1/5 \\
0.065 & 0.06
\end{array}
\]

Learnability \( B1.2 \)

\[
\begin{array}{ccc}
5 & 1 & 1/2 \\
0.361 & 0.032
\end{array}
\]

Productivity \( B1.3 \)

\[
\begin{array}{ccc}
5 & 2 & 1 \\
0.574 & 0.045
\end{array}
\]

WV Weight vector and PV Priority Vector

2.2.3 Level C: Alternatives
Analysis with respect to B1.1= Impact

Weight of B1.1=0.0057, refer to weight vector B1

<table>
<thead>
<tr>
<th>Criteria A1</th>
<th>C1</th>
<th>C2</th>
<th>Priority Vector</th>
<th>Weighted Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>LabVIEW</td>
<td>1</td>
<td>3</td>
<td>0.75</td>
<td>0.004257</td>
</tr>
<tr>
<td>MATLAB</td>
<td>1/3</td>
<td>1</td>
<td>0.25</td>
<td>0.001425</td>
</tr>
</tbody>
</table>

2.2.4 The aggregate vectors
Calculation for the alternatives relative to the A1 = General

<table>
<thead>
<tr>
<th>Analysis with respect to:</th>
<th>Aggregate Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1.1</td>
<td>B1.2</td>
</tr>
<tr>
<td>LabVIEW C1</td>
<td>0.004257</td>
</tr>
<tr>
<td>MATLAB C2</td>
<td>0.001425</td>
</tr>
</tbody>
</table>

2.2.5 The aggregate matrix

\[
\begin{array}{cc}
A_1 & 0.143 & 0.074865 \\
A_2 & 0.31473 & 0.0718 \\
A_3 & 0.18128 & 0.1353 \\
A_4 & 0.039777 & 0.038925 \\
\hline
\text{Sum} & 0.679 & 0.321
\end{array}
\]

2.2.6 The final priority vector

This vector shows the preference of LabVIEW (67.9%) over MATLAB (32.1%)

\[
\begin{array}{c}
C1 = 0.679 \\
C2 = 0.321
\end{array}
\]

2.3 Analysis of Results

Structuring the problem in the way the AHP process required not only makes the problem formulation easy but also makes it clear which criteria or sub-criteria influence the final decision. The final decision, which can be extracted from the final priority vector, shows the preference for LabVIEW over MATLAB according to the entered judgements at each level. The judgements in the lowest level of the hierarchy influence greatly the final decision; however, the relative importance between criteria in each level increases or decreases the contribution of the initial judgements in the lowest level. Figure (3) shows the percentage contribution of each criterion in the final decision. It is clear from this figure that the influence of the technical advanced criteria has more effect than the other criteria in which the percentage contribution reaches about 47% of the total percentage of the LabVIEW preference. The lowest contribution in the final decision in the A level criteria is shown by the general criteria for the LabVIEW preference which is the same for the MATLAB preference. The practical criteria contribution is the highest towards the MATLAB preference.

2.4 Sensitivity Analysis

Because the judgements made here are based on personal experience it is necessary to show how sensitive the preference for LabVIEW over MATLAB is to the change in the priority vector at each level. Any change in the priority vector means a change in the inherent judgements entered by the user. Therefore, identifying the relative importance of the entered values must follow any change in the priority vector.

Figure (4) shows the gradient graphs of the priority vectors of the main criteria and the effect of changes have been made to the preference of MATLAB and LabVIEW. It is obvious from this figure that there is no break-even point which indicates that changes to the individual priority vectors will not provide a preference for MATLAB over LabVIEW. However the general criterion gives a break-even point when it is the only criterion at this level. This shows that it is necessary to go to a lower level to change the priority vector.
Figure (5) shows example gradient graphs for B1 criteria, it is obvious that a break-even point can be achieved for different sub-criteria, which implies the possibility of changing the decision at this level. A break-even point for certain criteria means an equal priority of the two alternatives. The change in one of the elements of the priority vector means proportional changes in the other elements to keep the judgements consistent. Analysis of the results shows that any positive change in the priority vector for the B2 criteria increases the preference of MATLAB over LabVIEW. Keeping the modularity sub-criteria priority, increasing the weight for the power and computability and reducing the weight for syntax reduction can achieve the preference for MATLAB over LabVIEW. This increase in MATLAB preference is due to the original preference of MATLAB in the sub-criteria B2.6 in which MATLAB is 5 times preferred to LabVIEW. Sensitivity analysis is a good tool for advising on the required change in priorities for a proper selection of tradeoffs.

3. NON-COMPARABLE FEATURES OF MATLAB AND LABVIEW

As the above analysis is based on pairwise comparisons it is necessary to identify other advantages that exist in one environment and not in the other. These advantages may support the use of one environment over the other if it is essential for the development.

3.1 MATLAB Advantages:

1. **Specialist toolboxes** - this feature enables the use of specially designed functions and to implement them directly in the program. For example, the robotic toolbox [Corke], the system identification toolbox, and the control toolbox contain powerful functions to reduce programming time. LabVIEW contains functions similar to some toolboxes such as signal processing, data acquisition etc.

2. **MATLAB C compiler**, this feature enables the user to convert MATLAB code into a C-code executable or dynamic link library (DLL). This enables real time operation for real time critical systems and facilitates stand-alone applications.

3.2 LabVIEW Advantages

1. The code interface nodes CIN, this feature enables the user to bring all the features of other programming languages inside LabVIEW. For example, MATLAB, HiQ and C interface nodes, which allow the implementation of existing c code inside programmes made with LabVIEW. The good thing in using this feature is for example using the powerful MATLAB toolboxes inside LabVIEW.

2. Another form of interface node is the dynamic link library interface node, which allows the interface of other software libraries. This in conjunction with the MATLAB c-compiler can bring the real time functionality of the MATLAB toolboxes inside LabVIEW.
3. Polymorphism is a feature in LabVIEW that allows the automatic change of data types without conflict.

4. DISCUSSION
For software development, the concepts of SE provide solutions to most of the interfacing and integration problems however the tools to carryout these concepts need to be identified. Two programming environments allow the use of these concepts namely, MATLAB and LabVIEW. The selection process for the most appropriate environment can be carried out using the AHP process, which requires the establishment of selection criteria. Pairwise comparison of criteria with respect to suggested alternatives provides a systematic way of decision-making. Pairwise comparisons can be obtained from users of the two environments or from other supporting information. A sensitivity analysis is needed to identify the change in the decision if any of the priority vectors change. The output from the AHP shows a preference for LabVIEW over MATLAB for the values considered in this study. Practically, Graphical Programming allows logical top-down architectural design and the decomposition of the software components. For ready-made components, which require the use of a specific data format, it is possible to use them directly thanks to the polymorphism of the data types in LabVIEW. It is possible to use top-down decomposition without the worry of the interfacing or changing the logical top down architecture. A crucial property available in Graphical Programming is modularisation of the software package components. Modular design requires clear interfaces between the system modules; the versatility of Graphical Programming provides different interfaces, which allow easy integration of the software package components. For example, in the case of the Starlifter controller software, the MATLAB robotics toolbox is used for kinematics calculations.

5. CONCLUSIONS
The AHP process provides a good systematic tool for decision-making in case of multiple criteria problems such as software development. A software development environment should satisfy robotic systems development principles, which are based on systems engineering principles. Architectural design, modularisation and prototyping are important concepts that should be employed in the software development process. Selecting an appropriate software development environment involves many issues, which depend mainly on experience. However using the suggested criteria helps in the decision to select a particular programming environment. Sensitivity analysis on the priority vector provides a good tool for supporting the final decision by examining the shift in decision caused by the preference of one criterion over others. The results obtained from the AHP process reflect the practical situation in which it was found that graphical programming provided powerful capabilities to assist in the rapid development of software for construction robots.

6. REFERENCES


Monitoring Roller Vibration During Compaction of Crushed Rock

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ABSTRACT: Real-time monitoring during soil compaction can be made possible by utilizing the vibration signature of a vibratory roller compactor. The compactor and soil constitute a coupled dynamic system, albeit complex and nonlinear. As the soil density increases and its mechanical properties change, the dynamic response of the compactor will change. Developing a thorough knowledge of the relationship between compactor vibration and soil properties has the potential to enable real-time monitoring of desired mechanical soil properties (e.g., resilient modulus) and subsequently intelligent compaction, wherein the forcing amplitude and vibration can be varied to optimize the compaction process. This paper presents the results of vibration monitoring during roller compaction of crushed rock (well-graded sand). Vibration monitoring revealed that drum vibration amplitude is mildly sensitive to increase in underlying material stiffness. Harmonic content, reported as total harmonic distortion, increased with greater sensitivity as the underlying soil densified and stiffened.


1. INTRODUCTION

Vibratory compaction of geomaterials via plate, tamper, or drum roller is a widely accepted soil improvement method used to achieve the target density (e.g., standard or modified Proctor) and thus the mechanical properties (i.e., resilient modulus, shear strength) of the medium. The significant dynamic forces created by eccentric vibration at frequencies up to 60 Hz exceed the static forces by factors up to five and thus provide the necessary shear stress and acceleration levels to densify and improve the properties of geomaterials.

The proliferation of intelligent systems, prompted by the availability of technology and the desire for improved performance and efficiency, has begun to permeate transportation earthwork construction (e.g., autonomous construction field operation via GPS navigation and GIS mapping). The ability and cost efficiency of sensors, on board micro-processing, and wireless transmission makes feasible intelligent systems that can sense their environment and adapt to improve performance. Currently, vibratory compaction practice in the U.S. does not utilize the sensing and adaptation inherent in intelligent processes. Real time assessment is not integrated into the compaction operation; rather, the only quality assurance and quality control (QAQC) measures are performed independently at discrete locations that amount to well under 1% of the total area being compacted. Hence, compaction practice remains crude, labor-intensive and time-intensive. Soil compositions and behavior vary greatly even within a single construction job. Current practice requires that site-specific compaction guidelines (e.g., target moisture content and density, required number of passes) must be determined for each soil composition through extensive calibration by skilled technicians. An operator guides a compactor at a discretionary forward velocity over thin lifts of soil. The magnitude and frequency of the dynamic force (via eccentrics within the drum) are typically pre-determined and remain constant during operation. QAQC specifications require frequent verification of density and water-content, generally by a nuclear density gage-certified technician. The lack of integration between the compaction process and QAQC leaves costly under- and over-compacted areas.

The shift towards performance-based construction specifications places the onus on the designers and contractors to provide a product that will perform throughout its intended life (e.g., warranties). Performance-based compaction requires the deliverance of mechanistic soil properties (e.g.,
resilient modulus, shear strength, permeability) rather than the surrogate density and moisture content alone.

The use of vibration data to interrogate the health or condition of systems (e.g., machinery, structures) is part of the growing field of study of structural health monitoring [1]. The effective use of a compactor's vibration characteristics to assess the mechanical properties of the involved soil constitutes a form of continuous quality control or health monitoring. To develop performance based intelligent vibratory compaction techniques via vibration monitoring, a great deal must be learned about the response of the coupled compactor-soil system and the relationship between compactor and soil response. While on-board “compaction meters” that monitor drum vibrations are gaining acceptance in practice [2,3], the knowledge base surrounding the relationship between compactor vibration behavior and soil condition is not well developed.

The coupled compactor-soil system is nonlinear and pseudo-transient. There is little published data regarding the relationship between compactor and soil vibrations, the effect of frequency and amplitude on soil and compactor vibrations, and the nature of nonlinear soil behavior when subjected to vibratory compactor loading [4,5]. Previous studies of plate compaction have illustrated a relationship between vibration amplitude and level of compaction [6]. This research also revealed consistent trends in the evolution of harmonic content with soil compaction [6]. This paper presents some findings observed during monitored vibration on crushed rock test beds, with feature extraction from time and frequency domains. The results focus on drum and frame vibration amplitudes as well as harmonic content arising from the nonlinear system response.

2. EXPERIMENTAL SETUP

The test procedure is briefly described below; see [7] for a complete description. An Ingersoll-Rand Corporation SD-100D smooth drum (2.1 m wide, 1.5 m diameter) roller was used during the investigation (see Fig. 1). The SD-100D has an operating weight of 101-kN and a drum weight of 36-kN. Rotating eccentrics within the drum create the vibration force. Vibration frequencies range from 10 to 40 Hz; the vibration force can reach 200-kN under low amplitude settings. Depending on the soil properties, this can cause decoupling (bouncing) between the drum and ground. The roller drum and frame were instrumented with Summit Instruments (Akron, OH) and Crossbow (San Jose, CA) triaxial accelerometers aligned to measure vertical and horizontal (2 directions) acceleration. The low noise (5-10 mg rms), high sensitivity (200-420 mV/g) accelerometers measured drum and frame acceleration within a range of ±10 and ±7.5g, respectively. Acceleration data was sampled at 1 kHz and collected via a 16-bit National Instruments™ DAQ-card and laptop computer. Both time domain and frequency domain analysis were performed on the drum and frame acceleration data to explore the sensitivity of various signal features to the soil compaction process.

Figure 1. Ingersoll-Rand Vibratory Drum Roller

The results of compaction tests performed on well-graded sand (termed “crushed rock”) are presented in this paper. The instrumented vibratory roller was driven over 10-m long by 7-m wide soil beds carefully prepared with tilling equipment to prepare homogeneous loose soil typical of an earthwork construction environment. The soil beds were each prepared by tilling an approximately 300-mm thick soil lift to a homogeneous state. The subsurface beneath the crushed rock (CR) lifts was extremely stiff compacted gravel that served as a staging area for dump trucks, graders and loaders. Once the soil was tilled to a homogeneous loose state with the desired water content, a single pass of the compactor was performed (see Fig. 2). The forward velocity of the compactor was held constant at 0.5 m/s; however unavoidable variations in forward velocity did occur. Density, moisture content, and dynamic cone penetration testing were then conducted at two marked bed locations, 25% and 75% along the length of the bed. The dynamic cone penetrometer (DCP) was

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used to assess soil stiffness and strength (see Fig. 2). The impact force from a free-falling weight drives a DCP tip into the ground. The resulting dynamic penetration index (DPI) is defined as the amount of penetration (cm) per hammer blow. DPI has been correlated to resilient modulus and shear strength of soil [8]. This process of rolling and testing was repeated until the desired state was achieved (typically 5-8 passes).

3. TEST RESULTS

Vibration was monitored during the compaction of three crushed rock test beds – CR1, CR2 and CR3. Vibration frequencies for the three tests ranged from 20 to 28 Hz. At the 25% and 75% marks, 2-second data files were extracted from each full-pass data file. Given the forward velocity of 0.5 m/s; each data file was consistent with 1-m of machine travel. Figure 3 illustrates the drum and frame acceleration amplitudes in the vertical and horizontal directions at the 75% mark during passes 1 (partially compacted) and 5 (compacted) on test bed CR1. Peak amplitudes of drum and frame acceleration in both the vertical z (upward and downward) and horizontal x (forward and aft) directions are presented. Positive values indicate upward and forward acceleration while negative values indicate downward and aft acceleration. Each data set is presented at a similar scale to allow visual comparison. The eccentric mass assembly rotates in a forward direction (i.e., with the same trajectory exhibited by the drum rotating as it would move forward); therefore, the xz-diagrams are produced by clockwise motion.

Figure 3 illustrates the consistent trends observed during compaction: (1) downward drum acceleration exceeds upward drum acceleration; (2) drum acceleration amplitude increases as the underlying medium stiffens. The drum acceleration depicted in Figure 3 undergoes significant change from pass 1 to pass 5 – increasing acceleration in both vertical and horizontal directions. It should be noted that the vibration frequency did increase from approximately 23 Hz during pass 1 to 25 Hz during pass 5; and hence, contributed somewhat to the increase in acceleration amplitudes.
Vertical drum acceleration amplitudes are plotted versus DPI for each CR bed in Figure 4. Though there is considerable scatter in the data, Figure 4 reveals a general trend wherein the drum acceleration increases as the DPI decreases (and the soil stiffens). During compaction of crushed rock, the downward drum acceleration was much greater (up to 50%) than the upward drum acceleration. Down acceleration amplitudes also exhibited less scatter. The vibration frequency also varied considerably within passes of the compactor and from pass to pass. To remove this variability due to vibration frequency, peak-to-peak acceleration amplitudes were normalized by the vibration force. The resulting normalized drum accelerations ($\ddot{a}\text{ (p-p)/F}_{\text{vib}}$) are presented in Figure 5. Figure 5 illustrates only a mild increase in normalized acceleration amplitudes with underlying stiffness. These results are consistent with findings during compaction on other sand sites [9].

Frequency domain analysis of the vibration data was performed via FFT to investigate harmonic content as a measure of system nonlinearity. FFT analysis was performed on the two-second data files recorded at the 25% and 75% marks for each pass over test beds CR1-CR3. The frequency content was assumed to be constant during each 1-m long, 2-second interval. Harmonic amplitudes $A(f_i)$ were tabulated, where $A(f_1)$ is the amplitude of the fundamental (operational) frequency, $A(f_2)$ is the 1st harmonic amplitude ($2 \times$ fundamental frequency), etc. The total harmonic distortion (THD) provides a measure of collective harmonic content. THD is defined as:

$$\text{THD} = \frac{\sqrt{A(f_2)^2 + A(f_3)^2 + \cdots + A(f_N)^2}}{A(f_1)} \times 100$$ \hspace{1cm} (1)

Values of $A(f_3)$ through $A(f_N)$ were found to be insignificant compared to $A(f_2)$; hence, the THD essentially reflects the ratio $A(f_2)/A(f_1)$. THD values observed during compaction of crushed rock test beds are presented in Figure 6. Though scattered, the THD values increased from 8-18% during compaction of crushed rock beds.

4. SUMMARY AND CONCLUSIONS

To monitor vibration during compaction, the drum and frame of an Ingersoll-Rand compactor were instrumented with accelerometers. Vibratory compaction was carried out on carefully prepared beds of crushed rock to explore vibration characteristics and changes therein as the soil stiffens during compaction. Time-domain drum and frame acceleration amplitudes were fairly insensitive to changes in underlying material properties. During soil compaction, normalized drum acceleration values increased slightly (less than 10%) as the DPI more than doubled.
Harmonic content, measured during vibration and expressed as normalized frequency components and THD, exhibited greater sensitivity to changes in underlying material properties. THD essentially doubled during compaction of crushed rock.

These test results provide some promise for the effective use of real time monitoring of soil compaction. However, machine sensitivity to changes in soil properties during compaction was found to be subtle. Operational variability issues present a challenge to vibration based soil compaction monitoring. Fluctuations in vibration frequency, forward velocity, local variability in soil moisture and composition, and depth and stiffness of underlying strata all effect vibration characteristics. Machine variability can be addressed via control technology; however, the analysis techniques will have to be further developed to minimize the unavoidable soil variability.

5. ACKNOWLEDGEMENTS

The authors are very grateful to the Oklahoma Department of Transportation and the National Science Foundation (CMS-9984378) for providing funding for this research program. The authors would also like to express their appreciation to the Ingersoll-Rand Corporation for providing the vibratory roller compactor used in this study.

6. REFERENCES


A risk model for pile foundations

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ABSTRACT: This paper describes a model which has been developed for the purpose of assessing major risks associated with various pile foundation types and their resulting financial consequences. The work is based on a review of possible geotechnical sources of risks encountered during the placing of pile foundations. Both literature and experts are used in order to compile lists of risks associated with the different types of piling methods. The model is intended to support geotechnical designers or contractors in making sound decisions as to the selection of piling foundation types that are appropriate to the specific situations at hand.

The study has identified four major groups of risk events that can be possibly encountered when producing a specific pile foundation type; damage to surroundings, damage to the piles themselves, incorrect piles placements and damage to equipments.

The study has also identified the parameters that have influence on the presence and magnitude of the undesired events. The research uses influence diagrams to model these events and to create what is termed as a risk network. A computer program, based on Bayesian probabilistic approach, is used to produce such a network whereby risks can be quantified in terms of costs and delays.

The paper describes application of the model and draws conclusions on the results produced and the usefulness of the developed model as a tool for supporting design and construction decisions.

KEYWORDS: Risk model, Geotechnical design, Pile foundations

1. INTRODUCTION

Uncertainties and risks are identifiably inherent in construction work. They complicate the decision making process particularly if decisions are required to be taken at an early stage in the project, when information available is minimal. This is certainly the case in the construction of pile foundations whereby, in the absence of all the information, foundation systems are often selected without informed decisions about potential and damaging risks (Hayes, 1987). For example there is no structured and explicit approach that considers risks during the design or the construction of pile foundations. There are also no suitable models or tools that enable efficient and effective risk management for this purpose. The knowledge on risks is not shared and stays in the minds of geotechnical experts. Even when such knowledge is available within construction companies, it is often not structured or available in ready-to-use format. All of this may cause technical problems and hence considerable additional costs. There is therefore a need for improved and informed decisions whereby the effects of risks on the choice and construction of pile foundations are taken into considerations. This work suggests that this can be made possible through identifying, classifying of possible risks and undesirable events and the development of a model that is able to predict the consequences of the major events for each pile foundation type under consideration.

In general there are two types of project risk analysis that can be carried out, qualitative and quantitative. Each of these approaches has its advantages and disadvantages. For example the qualitative approach has the advantage that not a great deal of information is required and that risks
can by analysed in a broad spectrum. The disadvantage however is that no in-depth analysis of the risks can be carried out and hence no detailed information can be found on the exact consequences of the events underlying the risks. Quantitative risk analysis methods on the other hand offer the opportunity to achieve a detailed view of the consequences of the events that might take place during construction. A disadvantage of this approach however is that it is not suitable to be used for assessment of risk in a broader sense (Vermande, 1998).

In his work (Bles, 2003) has shown that both methods are required in order to make informed judgments regarding risks of the various types of pile foundations. A combination of both approaches has also been adopted in this research.

2. INFORMATION FRAMEWORK

The adoption of a suitable information structure is conditional to selecting and classifying major risks in a project in an orderly manner. The fact that many different pile foundations exist means that such structure is not readily available. Some risks apply to many pile types whilst others are only related to certain pile types. It was therefore necessary to create a framework whereby logical links between events and pile types can be created. The framework is shown in Figure 1.

Figure 1. Adopted information framework

Figure 1 indicates that each type of pile foundation can be linked to its construction activities and each activity is in turn linked to possible undesired events that are in turn linked to their influence parameters. These parameters influence the chances of events being occurred. The four sections of the framework are interrelated and have the following characteristics:

- The chosen information framework as described enables easy identification of the risks for a project.
- The events are logically connected to the pile foundation type. They are linked to the activities necessary to install the pile foundation. From this it follows that the size of risk will not depend on the type of pile foundation but on the activities required to construct this pile foundation.
- The use of activities, events and parameters provides the right abstraction level. All factors included in the risk analysis could be placed within the information framework using the structure described.
- The inclusion of influence parameters in the structure has meant that it possible to input estimates of risks that apply to the project under consideration. The probabilities of various events occurring are rather project specific and are reflected by the relevant parameters. Identifying project parameters enables the simulation of the project specific circumstances in the model.

3. RISK DATABASE

The information structure described in the previous section is ideally suitable to be placed in a database. To do this all relations between pile types, undesired events and influence parameters have to be known. These relations are stored in the database, providing the opportunity to select a list of events for each pile type. From this information it is also possible to show which parameters have influences on the events.

The relations between the types of pile foundations and the activities needed are ‘hard’ relations. This means that for a certain pile type these particular activities always apply in order to install the pile in the soil.

The other relations are not ‘hard’. A certain event will not necessarily occur doing a particular activity, only in some cases this event will occur. Therefore these are referred to as ‘soft’ relations. To reflect this, each relation is assigned a value; a weight value. A factor 5 means a high weight, a factor 1 represents a low weight. In this way it is possible to see in the database which parameters and event are most important to which pile foundation type. Most relations are found in literature, others are provided by experts. Based on the literature, initial values are assigned as weights to these relations. These values however are eventually adjusted using information provided by expert opinions. The majority of these values should be put into context. That is to say that the probability of occurrence of undesired event is not fixed and is to a large extend dependent on the specific situation in which the pile foundation is constructed.
4. RESEARCH METHODOLOGY

A Bayesian Belief Network (BBN) is used to model risks in this work. This is a method, which uses probabilistic theory for reasoning under uncertainty and risk in expert systems. The method provides the opportunity to set joint probability distribution functions to a set of stochastic variables, ordered in a network. This network shows the relations between the variables. Basically a BBN consists of two parts, a qualitative and a quantitative part. The qualitative part includes a graphical representation (network) of the relationships between the parameters. The quantitative part consists the assignment of conditional probabilities to all variables in a so-called likelihood-table. These tables describe the effects of preceding variables on the underlying variables.

The basis of BBN is provided by the Bayes-theorem of Thomas Bayes (Rouanet et al., 1998):

$$P(H_i \mid D) = \frac{P(D \mid H_i)P(H_i)}{\sum_i P(D \mid H_i)P(H_i)}$$

With this theory it is possible to calculate the probability of a variable within the network based on data from the Bayesian network. Despite

Working with Bayesian Belief Networks provides the following advantages:

- In spite of uncertainty it is possible to give a judgment on the expected risks.
- The networks provide the opportunity to implement both analytical and intuitive knowledge based on expert experience.
- Estimates based on only one expert is enough to provide a basis for a functional model.
- It is possible to build the networks step-by-step due to the fact that child-parent relationships are used. This also makes improvement and extension of a network possible.
- The graphical representation of the network makes it easy to understand, even for people not specialised in the field.

The major disadvantage of the BBN is that the conditional likelihood tables can easily become very large. For example, if we have three parameters with four conditions each affect another parameter then there are already 64 chances to be determined.

4.1 Research Delimitation

During construction of a pile foundation many undesired events might occur. The major risks are however determined by a few of these events. As long as it possible to make correct estimates of these major events, insights in the overall financial, time-dependent and qualitative consequences can be obtained. In this paper the quantitative risks results of only major events are presented. These major events are:

- Piles do not reach the required depth
- Damage to surrounding structures due to vibrations
- Damage to surrounding objects due to settlements caused by vibrations

The work also only cover the common three major pile types applied in Dutch practice. These include prefabricated concrete piles, the vibro-piles (vibration piles) and the bored piles. Together these piles have a market share of approximately 95% of the Dutch market.

4.2 Piles not reaching the required depth

An engineer designs a pile with a certain bearing capacity, including a required pile tip level. Due to a number of reasons a pile might have difficulty achieving the required depth. The worst case occurs when it is impossible to make the pile reach the required depth and therefore fail to achieve the structural requirements the pile is designed to meet. In these cases new attempts have to be made to install the pile or alternative measures have to be taken. Alternative measures may include, for example, pre-boring the new piles or changing the pile hammer. This can cause the piles to break or the pile heads to be damaged. The event described here may result in major financial and planning penalties. The problem may to stopping the construction work for a certain period of time, which in turn may lead to a considerable delay for the construction programme as a whole.

Interviews with experts have revealed that there are three main causes for not achieving the required pile depth; existence of obstacles in the ground; high soil resistance and damage to equipment. Damage to equipment may also be the result of the first two reasons. The more resistance encountered in the ground when installing a pile the higher the chance of equipment damage. On the basis of the above parameters it can be determined whether or not a pile can reach its
required depth. However, these are not the only reasons for the occurrence of such event and that there may be other circumstances, which contribute to this end. These can be referred to as ‘human factors’. The expertise of the construction team as well as the knowledge of the construction company of the local circumstances can play important role in this respect. Also the level of detail of the soil investigation has to be taken into account. A more intensive soil investigation increases the chance that the piles will achieve the required depth. The BBN network developed to model this event and determine whether a pile will achieve it’s required depth includes all these parameters as shown in Figure 2. Providing an estimate of the percentage of piles that will probably not achieve the required depth it would then be possible to calculate consequences in time and cost for the foundation.

4.3 Damages due to vibrations

Installation of a pile using a hammer causes vibrations in the ground, which can cause damages to structures or apparatuses around the construction site. The damage can also be in the form of hindrance to work and people in the proximity of the construction site. The BBN network which is developed in this work to represent this risk event and which is shown in Figure 3 only models the damage to adjacent structures.

The most important influence parameters when determining the potentials for damages are related to the distance from the source of vibration and the types of adjacent structures. Based on values and estimates given to these parameters, the damage due to vibrations can be calculated. The literature study has shown that more factors of influence exist. For this reason these are also included in BBN.

Based on the factors above the expectation value of the damage due to vibrations is calculated. This expectation value is, based on the construction type (monument, house, office building), translated into expected financial damage.

4.4 Damages due to ground settlements

Ground settlement due to the vibrations in the ground occurs when soil particles take different arrangements and bring about consolidation of the soil. The extent of the ground settlement is dependent on the extent of the vibration, the soil type and soil properties. As soon as a suitable combination of these occur, soil will consolidate and cause ground settlement and possible damage to adjacent structures. Even relatively small vibrations might results in settlements. The calculation of the settlements is performed using the model of Hergarden et al. (2001). Important input to this model is the acceleration of the vibration and the relative soil density. The extent of the damage to surroundings is dependent on the vulnerability of adjacent structures, namely the type of foundation.

The BBN for this event is shown in Figure 4.

5. APPLICATIONS AND TESTING OF THE MODEL

Located on an industrial area site in “Weststad III” in Oosterhout, the Netherlands, an industrial building has been constructed for a Dutch company (Martens Beton) in the year 2002. The site investigations have shown that a pile foundation was necessary. It has been decided to use prefabricated (reinforced, not pre-stressed) piles. In total the foundation consist of 1688 piles. Randomly some acoustic measures have been taken, using a dynamic pile-test method. From the random tests it was concluded that in one corner of the installed pile field (partly) broken piles existed, probably caused by mistakes during installation of the piles. After deliberation it is decided to install 6 extra piles.

The fact that the problem was found during the pile installation it was fairly easy to solve it and continue with the work without delay. Extra cost was paid which included more detailed acoustic measurements and deliberation among participants as well as installation of extra piles. In total the extra cost amounted to approximately € 4000. The case described above is simulated using the BBN “not achieving the required depth”. The results were that the expected percentage of piles not achieving the required depth is 2 percent and a subsequent cost of € 11,500 with a project delay of 2 weeks.

In comparison to what happened in reality, the expected percentage of piles not to achieve depth is high. From the BBN it followed that the cause for not achieving depth is not in the ground. The expectation from the network was that the piles would achieve the depth required. These results do match the case. The 2 percent of piles not achieving the required depth was fully related to the ‘human factors’. Because of the high percentage of piles not achieving the depth the
consequences in cost and delay were overestimated.
Using the same case the other network models have also been tested. The tests have shown that it is relatively easy to use the model and to estimate how high the costs are on the basis of single statistical parameters. Experts have validated the estimates of cost produced by these models as being reasonably accurate.
The effects of certain risk control measures on cost and time have also been calculated. It was shown that it is possible to use the developed model as a decision support tool to test the consequences of certain measures and decisions in a relatively short span of time.

6. CONCLUSIONS
The work described in this paper has shown that by separating the model into quantitative and qualitative parts it was possible to cover the more broad aspects of the subject as well as to be able to look in depth into some other aspects of undesired events.
The work has also shown that the risk database is suitable for use as a checklist of known undesired events. The database also serves to provide information on which parameters affect which events, hence enabling to roughly estimate the size of possible risks involved.
The developed Bayesian networks are easy to use as a decision support tool in risk management. They enable to provide quick estimates of the expected cost and time overruns. The effects of control measures considered are also easy to determine.
Testing of the model has shown that the model produced reasonably accurate risk estimates of reality.

The database and the Bayesian networks are not fully validated and although it is not expected that the structure of the networks will require major improvements, however the norms and conditional likelihood tables may need further refinements.

7. REFERENCES
Figure 2. BBN Not achieving the required depth

Figure 3. BBN Vibration damage

Figure 4. BBN damage by vibration induced settlements
Dynamics and monitoring of vibratory piling process

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\textbf{ABSTRACT:} The foundations of buildings in urban environments are very often piled ones. During earth moving works the sides of digging area have to be supported by sheet pile walls to maintain constant earth pressure conditions against existing foundations. The piles and sheet piles are very often driven by vibratory methods, in which case the ground vibration is a risk for neighboring old buildings. The purpose of the present research work is to find a new, theoretically well established way to use vibratory pile drivers environmentally friendly especially in urban environments. Closely related to this a new electro-hydraulic circuit has been introduced by Unisto company for on-line adjusting of the phase angle between primary and secondary shafts of eccentric masses in the vibratory unit. Furthermore, the control of this angle will be subjected to continuous monitoring from the vibration level of the critical structure to be protected. The control of shafts phase angle is based on separate drive technology, in which the position difference is governed by electrically controlled orifices. Vibration control principle is based on the requirement to stay below required vibration bounds in the working environment. The system is equipped with a vibration sensing box to be fixed on to the protected structure, from which the vibration level information is transmitted to the control box of vibratory unit. The described system is investigated both theoretically and numerically. The theoretical part of the research includes the derivation of complete system equations. In the numerical part of the work the system is coded and simulated by computer to get required information for system modifications and dimensioning. The main objective of these research steps is to evaluate the operation of phase angle adjusting system in order to balance the control of environmental vibrations and machine performance.

\textbf{KEYWORDS:} Vibratory pile driving, ground vibrations, fluid power systems

\section{1. INTRODUCTION}

Construction activity has been continuously increasing in areas where conditions for solid foundations are traditionally poor. Typical soft soils are common on river sides, where the urban settlement is historically very often concentrated. High prizing of land has increased the construction efficiency, the consequence of which is the design of tall and heavily founded buildings. The mostly used techniques are to cast pillars on site or to hit piles. Because both new constructions as well as rebuild structures are very often located between existing buildings, the foundation works have strong effect on the stability of neighboring underground structures. A very common solution is to isolate the area to be excavated by sheet pile walls in order to maintain the lateral earth pressure against the existing foundations. The wall consists of an assemblage of separate sheet pile elements locked to each other, each of which has to be hit in to the ground before the start of excavation works. The drive of sheet piles or foundation piles is mostly done in urban environments by vibratory methods instead of noisy hammering method. Vibratory driving method generates propagating
ground vibrations, which are transmitted to the neighboring buildings especially during speed up and slow down [Reusch]. In the worst situation the buildings may get displacements and cracks, both phenomena which are forbidden in the case of historically valuable buildings. Transmission of vibration to offices and apartment houses is also unwanted as it may cause disturbances and damages. Investigations have shown that high intensity vibrations at some vibration speed ranges are related to the passage of critical speeds of the pile – soil – building system.

Vibratory units typically consist of a pair of shafts driven by electrical or fluid power, onto which the eccentric masses are mounted to generate the vertical harmonic force excitation (figure 2). When applying a static driving force the pile penetrates into the ground with a speed depending on frequency and amplitude of the vibration.

The capacity of the unit may be multiplied by adding a number of shaft pairs. This brings the possibility to adjust the phase angle between the eccentric masses in order to continuously add or subtract the component forces. There exist few known mechanisms, with which the phase shift or the mass eccentricity can be varied in a desired way during the drive, thus making it possible to reach resonance-free up and down slides of the speed. One possibility is to use an additional torque motor assembled into the secondary shaft pair to move the angular position of the secondary shaft with respect to the primary one (figure 3). Another way is to vary mass eccentricity by a linear actuator moving the mass in radial direction.

Because centrifugal forces are quite large, the actuators installed in the rotating coordinate system need high power density as well. This can be produced by high pressure fluid power cylinders requiring rotating fluid connectors for power supply. The weak point of these arrangements is the frequent maintenance needs at the dynamic seals.

To overcome these problems a new electro-hydraulic way has been introduced and patented to control the vibratory driving process by two parameters, the speed of the primary shaft and the phase angle between the primary and secondary shafts. It has been proposed that the operator will adjust these parameters during the run. Because the interaction dynamics of mechanical, structural and hydraulic sub-systems is very complex, the industrial unit has to be equipped with an automatic operation monitoring system. The purpose of the paper is to investigate this solution in order to evaluate its feasibility to real working conditions.
2. SYSTEM DESCRIPTION

The adjustment circuit of the phase shift is based on the solution where eccentric shaft pair numbers 1 (the primary) and 2 (the secondary) are driven by separate hydraulic motors. The shaft pairs are mechanically connected to each other by a gear forcing them to rotate always at the same speed. The gear has a mechanical dead-zone of 180 degrees. If shaft pair 2 is actively pulling only and shaft pair 1 is passively resisting the shafts are in full 180 degrees phase shift and the resulting vertical vibratory force is zero. On the other hand, when shaft number 1 is pushing only and shaft number 2 is resisting the phase angle is zero and the resulting vertical force is the direct sum of the component forces. Intermediate values are reached by combining the pushing torque of shaft 1 and the pulling torque of shaft 2 in a desired ratio.

Because both shaft pairs are rotating with the same speed the only physical quantities which indicate the power taken from each motor are the line pressures. The phase angle is controlled by electrically governed valves, which actually work as elements dividing the hydraulic power between the motors. The reduction factor of the resulting vibratory force for each phase shift angles \( \Delta \phi = \phi_2 - \phi_1 \) is given by

\[
\frac{R}{2F} = \frac{\sqrt{1 + \cos \Delta \phi}}{\sqrt{2}}
\]  

A vibratory unit, with on-line adjustable vibration frequency and magnitude, can be flexibly linked to an operation monitoring system. This controls the running parameters based on information measured from the critical structure subject to vibrations (figure 5).

3. SYSTEM DYNAMICS

In order to analyze its behavior before building a physical prototype, the system has been modeled and simulated. The lay-out of the system is shown in figure 6.
The system degrees of freedom are the vertical position $y$ of vibratory unit and pile combination, the vertical position $Y$ of the frame and the angular positions of mass eccentricities of the shafts. The mathematical model of the mechanical sub-system consists of a group of 4 second order differential equations

$$M\ddot{y} + k(y - y) = -Mg - F_a$$
$$m\ddot{y} + \mu_c \dot{y} + \mu_{c2} \dot{y} + k(y - Y) = \mu_s s_i \dot{\phi}_1^2 + \mu_s \dot{\phi}_2^2$$
$$-m'g - F_s \text{sgn}(\dot{y}) + F_p$$

(2a,b,c,d)

$$I_1'\ddot{\phi}_1 + \mu_c \dot{\phi}_1 + \Psi(\phi_1 - \phi_2) = -g\mu_c c_1 + T_1$$
$$I_2'\ddot{\phi}_2 + \mu_{c2} \dot{\phi}_2 + \Psi(\phi_1 - \phi_2) = -g\mu_{c2} c_2 + T_2$$

where $c_i = \cos \phi_i$ and $s_i = \sin \phi_i$ and $F_a$, $F_s$ and $F_p$ stand for the feeding force, skin friction and point load of the pile [Launis]. Mechanical coupling of primary and secondary shafts is described by the dead-zone function

$$\Psi(x) = \begin{cases} 
Kx & ; \ x < 0 \\
0 & ; \ 0 < x < \pi \\
K(x - \pi) & ; \ x > \pi
\end{cases}$$

(3)

On the other hand, the hydraulic torques generated by the motors are given by

$$T_i = D(p_i^p - p_i^m)$$

(4)

The pressures of driving ($p$) and resisting ($m$) chambers are respectively

$$\dot{p}_i^p = \frac{q_i^p - D\dot{\phi}_i}{V}$$

(5a)

$$\dot{p}_i^m = \frac{q_i^m + D\dot{\phi}_i}{V}$$

(5b)

where the valve flows are

$$q_i^p = cu_i \sqrt{p_i^p - p_i^m}$$

(6a)

$$q_i^m = cu_i \sqrt{p_i^m - p_i}$$

(6b)

in which the $u_i$'s are the control inputs to the proportional flow control valves. Their current values are output from the vibration control block system.

4. SYSTEM MODEL

Analysis of the system can be carried out by means of numerical time integration. Because the elements and components in the system represent quite common parts in mechatronic systems, the system model can be built from existing library objects. Utilization of a modeling environment developed at Machine Dynamics Laboratory in Tampere University of Technology led to the system composition illustrated in figure 7.

![Figure 7. System composition in the object-oriented modeling environment.](image-url)

In order to keep pile vertical trajectory, the vibratory unit is horizontally locked in a vertical slider, which arrangement serves the modeling task only. The vibratory unit consists of sub-models for the eccentric shafts, for the frame and for the isolation rubber springs (figure 8).
The fluid power system is a composition of standard component models for valves and motors linked by fluid volumes in the pipes (figure 9).

The complete system model is an order independent list of calls to component models. This reads in Fortran 95 standard format as given below:

```fortran
SUBROUTINE MOVAXPILER (M_NAME,MEC,ARM,JOINT,GEAR,CYL,MOT,VAL,RAMP,PID,VOL,PRES)
C      Definitions for component structures
RECORD /MEC_STRUCT/ MEC
RECORD /ARM_STRUCT/ ARM(8)
RECORD /CONT_STRUCT/ JOINT(12)
RECORD /GEAR_STRUCT/ GEAR(3)
RECORD /HYMOT_STRUCT/ MOT(2)
RECORD /HYCYL_STRUCT/ CYL
RECORD /VOLUME_STRUCT/ VOL(8)
RECORD /DCV_STRUCT/ VAL(3)
RECORD /CTRL_STRUCT/ PID(3)
RECORD /SEQ_STRUCT/ RAMP(3)
C     Guiding frame
CALL MECBASE (M_NAME,"BASE",MEC,ARM(1))
C Vibratory unit
CALL MECARM (M_NAME,"F",MEC,ARM(2))
C Eccentric shafts
CALL MECBODY (M_NAME,"A",MEC,ARM(3))
CALL MECBODY (M_NAME,"B",MEC,ARM(4))
CALL MECBODY (M_NAME,"C",MEC,ARM(5))
CALL MECBODY (M_NAME,"D",MEC,ARM(6))
C Frame
CALL MECBODY (M_NAME,"F",MEC,ARM(7))
C Pile
CALL PILEARM (M_NAME,"P",MEC,ARM(8))
C Bearings
CALL REVOLUTE (M_NAME,"JO1",MEC,ARM(2),ARM(3),"NE2","NE1","NA1","NA2",JOINT(1))
CALL REVOLUTE (M_NAME,"JO2",MEC,ARM(2),ARM(4),"NE2","ND2","ND1","NB2",JOINT(2))
CALL REVOLUTE (M_NAME,"JO3",MEC,ARM(2),ARM(5),"NE4","NE3","NC1","NC2",JOINT(3))
CALL REVOLUTE (M_NAME,"JO4",MEC,ARM(2),ARM(6),"NE5","NE4","ND1","ND2",JOINT(4))
C Isolation springs
CALL REVOLUTE (M_NAME,"JO5",MEC,ARM(7),ARM(2),"NF2","NF1","NE5","NE6",JOINT(5))
CALL CONTACT (M_NAME,"JO6",MEC,ARM(7),ARM(2),"NF1","NF2","NE6","NE5",JOINT(6))
CALL CONTACT (M_NAME,"JO7",MEC,ARM(7),ARM(2),"NF4","NF3","NE8","NE7",JOINT(6))
CALL CONTACT (M_NAME,"JO8",MEC,ARM(7),ARM(2),"NF3","NF4","NE8","NE7",JOINT(8))
C Grippers
CALL REVOLUTE (M_NAME,"JO9",MEC,ARM(2),ARM(8),"NE10","NE9","ND1","ND2",JOINT(9))
CALL CONTACT (M_NAME,"JO10",MEC,ARM(2),ARM(8),"NE9","NE10","NP1","NP2",JOINT(10))
C Guiding slider
CALL INTSLIDE (M_NAME,"JO11","JO12",MEC,ARM(1),ARM(7),"NBASE1","NBASE2","NF5","NF6",JOINT(11),JOINT(12))
C Gears
CALL GEARTRA (M_NAME,"GEAR1",MEC,ARM(3),ARM(4),GEAR(1),0.D0,0.D0,0.D0)
CALL GEARTRA (M_NAME,"GEAR2",MEC,ARM(5),ARM(6),GEAR(2),0.D0,0.D0,0.D0)
CALL GEARTRA (M_NAME,"GEAR3",MEC,ARM(3),ARM(6),GEAR(3),0.D0,0.D0,PI)
C Sequence control
CALL DCV_RAMP (M_NAME,"DCV1",RAMP(1),VAL(1))
CALL DCV_RAMP (M_NAME,"DCV2",RAMP(2),VAL(2))
C Hydraulic motors
CALL HYDMOT (M_NAME,"MOT1",MEC,ARM(2),ARM(4),"NB2","NB1",VOL(1),VOL(2),MO1(1))
CALL HYDMOT (M_NAME,"MOT2",MEC,ARM(2),ARM(6),"NE4","ND1",VOL(3),VOL(4),MO1(2))
C Hydraulic volumes
CALL HYDVOL (M_NAME,"VOL1",MEC,VOL(1))
CALL HYDVOL (M_NAME,"VOL2",MEC,VOL(2))
CALL HYDVOL (M_NAME,"VOL3",MEC,VOL(3))
CALL HYDVOL (M_NAME,"VOL4",MEC,VOL(4))
CALL HYDVOL (M_NAME,"VOL5",MEC(VOL(5))
CALL HYDVOL (M_NAME,"VOLP",MEC,VOL(7))
CALL HYDVOL (M_NAME,"VOLT",MEC,VOL(8))
C Proportional valves
CALL SRV (M_NAME,"SRV1",MEC,ARM(7),VOL(1),VOL(2),VOL(3),VOL(4),VAL(2))
RETURN
END
```

5. CASE STUDY

The system model has been used for feasibility studies of the introduced vibration control system. The case study consists of runs, in which the performance of the phase shift control has been compared without and with the connection gear. In the first case the primary shaft pair is working as the “master” while the secondary “slave” shaft is trying to keep the phase shift as constant.
Figure 9. Phase shift of shaft pairs for continuous feedback control of the secondary shaft.

The response of the phase shift is given in figure 9. The response behavior shows that the dynamic interaction of the shaft pairs mounted on the same frame body is so strong that classical PID type controls are not able to keep the phase shift in the neighborhood of the desired value.

In the second case the connection gear has been used under independent sequence control of the shaft pairs. The response plot of the phase shift (figure 10) shows regular behavior in changes from full amplitude reduction, phase shift = 180 degrees, to maximum amplitude, phase shift = 0.

Figure 9. Phase shift between shaft pairs for open loop control of the gear-connected shaft lines.

The result shows that the mechanical dead zone works well together with the sequence control of the shafts. The lower and upper bound values of the dead zone are reached in the desired way. Thus resonance-free speed slides as well as maximum pile driving performance are available in a robust way. Continuous control of the intermediate values is, however, a much more challenging task, which has been left to the subject of further developments.

6. CONCLUSIONS

Even if by far less harmful to environment than hammering methods, the usual vibratory driving methods are still generating propagating ground vibrations which, especially during speed up and slow down phases, do not meet new restrictive constraints imposed for respecting urban environment. There is a further need to master vibration dynamics and particularly resonance crossing. This can be dealt with by using a new patented two parameter electro-hydraulic way for controlling vibratory driving process, where the parameters are respectively the speed of primary shaft and the phase angle between the two shafts. The dynamical equations representing this system have been set down, which includes the three mechanical, structural and hydraulic sub-systems and their interactions. To analyse the system and its feasibility in real world situation, a preliminary case has been studied which deals with the sensitive question of the coupling control of the two shaft pairs. The results are showing that in open loop case (i.e. independent sequence control of shaft pairs), the upper and lower bounding values of the dead zone are approached in desired way which does not limit pile driving performances. On the other hand, in closed loop case where the second shaft line is feedback controlled, maintaining the phase shift between shaft pairs to a constant value is not possible here for simple PID controller, and always leads to oscillatory motion around nominal values. This indicates the needs for more adapted controller to better manage the interaction between shaft pairs.

7. REFERENCES


ABSTRACT: A number of piles should be driven into the ground by a hammering process in order to make the ground under the structure safe and strong when construction companies build a high structure such as building and bridges. It is essential to determine whether piles are penetrated into the ground enough to support the weight of the structure since ground characteristics at different locations are different each other. This paper proposes a high-speed real-time visual measurement approach for pile movement under hammering by combining a high-speed line-scan camera with a specially designed mark to recognize two-dimensional motion parameters, position and orientation, of a pile. A mark stacking white and black right-angled triangles is used for the measurement, and movement information for vertical distance, horizontal distance and rotational angle is determined simultaneously. Especially, a high-speed line-scan CCD camera whose line rate is greater than 10 KHz improves the measurement performance of dynamic characteristics of a pile at impact instant dramatically.

1. INTRODUCTION

Non-contacting visual measurement takes much attention since the measurement can be done safely without human intervention. It is possible to find many applications such as three-dimensional environments reconstruction and measurement of an object, posture determination of electronic components, and visual tracking of an object [1][2][3]. In most vision applications two-dimensional image sensors are used for the measurement but high-speed line cameras are adopted when dynamic motion of an object is considered since the measurement performance of two-dimensional image sensors – speed and accuracy - is constrained by image grabbing speed and imaging resolution of video cameras. Especially, blurring of images is happened and the size of image data is very huge in case of two-dimensional image sensors when the high-speed motion of an object is expected in images. So, in order to measure high-speed vibration characteristics of an object, there have been used two approaches using an acceleration sensor or a laser sensor. Specifically, when a construction company builds a high structure, many piles should be driven into the ground by a hammer in order to make the ground under the structure safe and strong. Therefore, it is essential to determine whether a pile is penetrated into the ground enough to support the weight of the structure since ground characteristics at different locations are different each other. Normally, when the penetration depth of the pile for ten hammerings is less than 4 millimeters, the constructor finishes the pile driving process. There have been proposed three approaches to measure the penetration and rebound movement of a pile. The first is a manual approach. After a worker attaches a white sheet on the pile, the worker draws a horizontal line slowly until a hammering process is finished. Then, the worker can obtain a graph for the vertical movement of the pile since the vertical motion of the pile changes the height of the white sheet during the hammering. The worker is, however, very dangerous since the hammering task is done over the head of the worker by using a hammer whose weight is greater than 7,000 Kg. The analysis of the movement is impossible since there is no quantitative data for the movement. The second way is to measure the movement...
characteristics by attaching an accelerometer sensor on the pile. Since the accelerometer sensor outputs acceleration information of an object, the distance of penetration and rebound movement of the pile is determined by integrating doubly the acceleration information. It requires a time-consuming process, however, to fix the accelerometer sensor on the pile and the sensor data is noisy when horizontal vibration of the pile is included. The approach provides the data only for vertical movement of a pile. Another way to measure the distance of penetration and rebound movement of the pile is based on a speckle laser sensor [4] because the speckle laser sensor is effective to measure the vertical movement of an object. Distance information of vertical movement can be obtained from the sensor data directly. The measurement resolution is 0.25 millimeters while its sampling rate is 8 milliseconds. So, it is not easy to observe the details of dynamic characteristic of the pile movement at impact instant between the pile and the hammer since the rebound process takes a very short time less than 1 millisecond. Also, only one-dimensional measurement is possible.

In this paper, a high-speed real-time visual measurement system for pile penetration and rebound movement is proposed by combining a high-speed line-scan camera with a specially designed mark to recognize two-dimensional motion parameters – vertical movement, horizontal movement and rotational movement - of a pile. A simple mark stacking white and black right-angled triangles is used for the measurement, and two-dimensional motion parameters are acquired simultaneously. Especially, by adopting a line-scan CCD camera whose line rate is greater than 10 KHz, the measurement performance of dynamic characteristics of the pile at impact instant is improved dramatically comparing with other approaches. And, the measurement data for two-dimensional motion parameters shows successful applications of the proposed system for real construction field.

Section 2 introduces measurement principles and equations for two-dimensional motion parameters of a pile by using a proposed mark. Section 3 includes an edge-tracking algorithm while experimental results for a spring system and a real pile penetration system are shown in section 4. The paper is concluded in section 5.

2. MEASUREMENT EQUATIONS

For the measurement of two-dimensional motion parameters of a pile using a line-scan camera, a mark is developed by stacking white and black right-angled triangles repetitively as shown in Fig. 1. A line-scan CCD camera grabs a line image by scanning from the top to the bottom of the mark attached on the pile.

Referring Fig. 2, it is possible to determine the coordinates of intersection points between the lines in the mark and the scan line of the line-scan camera in image plane. Here,

\[ H : \text{Height of the mark}, \]
\[ W : \text{Width of the mark}, \]
\[ \{M\} : \text{Reference coordinate frame for measurement}, \]
\[ \{T\} : \text{Transformed coordinate frame of } \{M\}. \]

Figure 1. Proposed Mark for Measurement

\[ y = ax + b \]

Figure 2. Used Coordinate Frames

\{T\} is used to overcome the singular case that the y-axis of \{M\} is parallel to the scan line of the line-scan camera. The line expressed by \( y = ax + b \) in Fig. 2 represents the scan line of the line-scan camera.
camera with respect to \( \{T\} \). Then, if parameters of the line, \( a \) and \( b \), are determined, the movement parameters for the mark can be calculated by using five intersection points between the mark and the scan line. When the rotational angle between two coordinate systems is set by 45 degrees as shown in Fig. 2, equations for the \( n \)-th horizontal and slanting line of the mark in \( \{T\} \) are expressed as follows, respectively.

\[
y_{nH} = -x + n\sqrt{2}H
\]

\[
y_{nS} = -\frac{1}{W + H}(W - H)x + n\sqrt{2WH}
\]

Then, the coordinates of two intersection points between the scan line and the \( n \)-th black triangle of the mark in Fig. 2 is determined as follows.

\[
P_{nH} = \left(\frac{n\sqrt{2}H - b}{a + 1}, \frac{n\sqrt{2a}H + b}{a + 1}\right)
\]

\[
P_{nS} = \left(\frac{n\sqrt{2WH} - b(W + H)}{(a + 1)W + (a - 1)H}, \frac{n\sqrt{2a}WH + b(W - H)}{(a + 1)W + (a - 1)H}\right)
\]

Summing up, the ratio of the length of the \( n(m) \)-th white band of the mark with respect to the length of \( n(m) \)-th black band determines the line parameters, \( a \) and \( b \), as follows.

\[
a = \frac{(L_m - L_n)W + (L_m + 1)(L_n + 1)(n - m)}{(L_m - L_n)W + (L_m + 1)(L_n + 1)(1)}H
\]

\[
b = \sqrt{2WH(nL_n + 1 - nL_m)}
\]

Here,

\[
L_n = \frac{D(P_{nH}, P_{nS})}{D(P_{nS}, P_{nH})} = \frac{(a + 1)W + (a - 1)H}{n(1 - a)H - \sqrt{2b}} - 1,
\]

\[
L_m = \frac{D(P_{mH}, P_{mS})}{D(P_{mS}, P_{mH})} = \frac{(a + 1)W + (a - 1)H}{m(1 - a)H - \sqrt{2b}} - 1.
\]

The \( D(P, Q) \) is Euclidian distance between two points \( P \) and \( Q \) in a plane. Based on the above concept and equations, the following relationships to determine the motion parameters of the mark are derived by using the image of single line shown in Fig. 3. The five edge points in central area of the image are used. Let \( n = 0 \) for a slanting line representing the nearest upper white-to-black edge with respect to the center of the image. At first, it can be found

\[
L_0 = \frac{D_{1H} - D_{0S}}{D_{0S} - D_{0H}} \quad \text{and} \quad L_1 = \frac{D_{2H} - D_{1S}}{D_{1S} - D_{1H}}
\]

Then,

\[
a = \frac{(L_0 - L_0)W + (L_0 + 1)(L_0 + 1)H}{(L_0 - L_1)W + (L_0 - L_1)H + (L_0 + 1)(L_0 + 1)H} - \sqrt{2WH(L_0 + 1)}
\]

\[
b = \frac{(L_0 - L_1)W + (L_0 - L_1)H + (L_0 + 1)(L_0 + 1)H}{(L_0 - L_1)W + (L_0 - L_1)H + (L_0 + 1)(L_0 + 1)H}.
\]

So, we can determine the coordinate of the center point of the line-scan camera image by referring Fig. 3 as follows.

\[
R_C = \frac{R_{PH}}{R_{PH}} + (1 - R)R_{0H}
\]

where

\[
R = \frac{D_{1H} - D_{center}}{D_{1H} - D_{0H}}.
\]

Consequently,

\[
P_{cH} = \left(-\frac{b + \sqrt{2}HR}{a + 1}, \frac{b + \sqrt{2}aHR}{a + 1}\right)
\]

since

\[
P_{0H} = \left(-\frac{b}{a + 1}, \frac{b}{a + 1}\right) \quad \text{and} \quad P_{1H} = \left(-\frac{b}{a + 1}, \frac{b + \sqrt{2}aHR}{a + 1}\right).
\]

In order to endow the equations with the time, the
initial coordinate of the center point and the coordinate of the center point at time \( t \) are described as follows.

\[
P_{C0} = \left( \frac{-b_0 + \sqrt{2}HR_0}{a_0 + 1}, \frac{b_0 + \sqrt{2}a_0HR_0}{a_0 + 1} \right) \\
P_{Ct} = \left( \frac{-b_t + \sqrt{2}HR_t}{a_t + 1}, \frac{b_t + \sqrt{2}a_tHR_t}{a_t + 1} \right)
\]

Finally, incremental linear movements of the center point of the line-scan image and incremental rotational movement of the scan-line of the line-scan camera compared to initial conditions of visual measurement in the coordinate frame \( \{M\} \) are determined by the following equations. Actually, the incremental linear movements are divided into two linear motions, one motion parallel to x-axis of \( \{M\} \) and the other motion parallel to y-axis of \( \{M\} \).

Here, let

- \( \Delta x_t \): Incremental movement parallel to x-axis of \( \{M\} \),
- \( \Delta y_t \): Incremental movement parallel to y-axis of \( \{M\} \),
- \( \Delta \theta_t \): Incremental rotational movement with respect to the center point of the line-scan image.

Then,

\[
\begin{align*}
\Delta x_t &= \left( \cos(\theta_0 - \pi / 2) \sin(\theta_0 - \pi / 2) \right) \left( P_{C0} - P_{Ct} \right) \\
\Delta y_t &= \left( \sin(\theta_0 - \pi / 2) \cos(\theta_0 - \pi / 2) \right) \left( P_{C0} - P_{Ct} \right),
\end{align*}
\]

\[\Delta \theta_t = \tan^{-1} \left( a_t - \tan^{-1} a_0 \right)\]

where

- \( \theta_0 = \tan^{-1} a_0 \),
- \( a_0 \): Slope of the scan line at initial time in \( \{M\} \),
- \( a_t \): Slope of the scan line at time \( t \) in \( \{M\} \).

The major advantage of the proposed approach is the fact that the slope and y-intercept of a scan line can be determined by dimensionless ratios between two lengths and there is no need for camera calibration.

3. EDGE TRACKING

In order to find and track five edge points of the mark in continuous images three-step image processing algorithm is proposed by combining thresholding of gray-level images, edge detection and edge tracking.

The threshold value to obtain binary images from gray level images has to be determined carefully since the brightness of images is distorted by the used zoom lens. The zoom lens is adopted in order to increase the accuracy of measurement but the brightness of images is distorted by the zoom lens since its magnification ratio is large. That is, the brightness of boundary area of the images is darker than the brightness of central area. So, it should be cleared by using multiple windows for thresholding. Fig. 4 shows an example for setting of multiple windows. Threshold values for binarization of three windowed regions are determined independently by using Otsu’s optimal thresholding algorithm [5].

Edge detection is to detect white-to-black edges and black-to-white edges after thresholding in initial stage while edge tracking is for following each edge point when the motion of a pile is beginning by hammering. Since the images are one-dimensional data, the edge detection is to find rising or falling edges in binary images.

![Figure 4. Windows for Thresholding](image)

After initial edges are extracted from a binary image, exact location of each edge is determined by differentiating images for a small region in the near of the initial edge point. The point whose differential value is greater than a threshold is determined as an edge point.

For edge tracking, it is assumed that linear movement per sampling time is less than half of the height of a triangle in the mark. The new location of an edge is located by using binary search algorithm [6] in a bounded area based on the assumption. During edge tracking, if the absolute value of cumulative vertical movement from the beginning
of hammering is greater than the quarter of the vertical view range of the video camera, new five edge points in the central area of an image are selected.

4. EXPERIMENTAL RESULTS

The measurement system is composed of a high-speed line-scan CCD camera DALSA CL-P1 equipped with a zoom lens and a 866 MHz Pentium III personal computer including a frame grabber, Matrox Meteor-2/DIG, for digital cameras as shown in Fig. 5. The resolution of the camera is 4096 pixels per line while its line rate is set as 10 KHz. The height of a triangle in the mark is 40 mm while the width is 200 mm.

![Figure 5. Measurement System](image)

Fig. 6 shows an example image of 1000 lines obtained from the line-scan camera when the mark is at rest. A row means a scan-line while the left-hand side is the top of the mark and the right-hand side of the mark is the bottom of the mark. It is observed that the brightness condition is distorted by lens at the left-hand and right-hand boundary.

![Figure 6. Scanned Image for 1000 lines](image)

Since the sensitivity of the CL-P1 line-scan camera is low, a 500-watt halogen lamp is used for measurement. At the outside of buildings, sunlight brighter than 5000 lux is sufficient to obtain good images to process. When the weather is cloudy or rainy, external bright illumination is essential for the measurement.

At first, we measure the vertical movement of z-stage by moving the stage upward continuously in 0.5-millimeter step in order to measure the accuracy of the proposed measurement system and to analyze measurement errors. The maximum absolute values of measurement errors are less than 120 micrometers inside buildings. It is reasonable considering the natural vibration of buildings and vibration of the motorized z-stage for exact positioning. Next, the measurement test using a spring system is done successfully by generating high-frequency vertical motions through manual hammering after attaching a mark on the plate fixed to the spring system.

Finally, we have obtained measurement data of horizontal, vertical and rotational movement of a cylindrical pile under hammering in a real construction place. The weight of the hammer is 7,000 Kg while initial distance between the hammer and the top of the cylindrical pile is 2 meters. The real experimental environment is shown in Fig. 7 including a line-scan camera and a mark attached on a pile while Fig. 8 shows the measured data for 11 hammering. The motion of rebound and penetration of a pile is shown clearly. Despite the rebound of the pile is observed at each impact, the pile is penetrated into the ground in average sense. The vertical movement of a pile after an impact is composed of four intervals composed of penetration region at impact instant, rebound region after impact, settling region after rebound, and release region that the hammer is going upward for next impact. The motion characteristic in settling phase is determined by the vibration of the pile itself and ground conditions.
Fig. 9 shows the motion trajectory of the attached mark in XY coordinate frame for a hammering. X-axis represents the horizontal motion of the pile and Y-axis shows the vertical movement of the pile during hammering. The largest penetration motion is the first movement after hammering and the movement is reduced continuously. Three large repelling motions of the pile by the ground are shown in Fig. 9. Since the sampling time for measurement is 100 microseconds, construction experts can investigate the dynamic characteristics of a pile in detail comparing with other equipments using laser sensors or accelerometers. Also, it is observed that the real penetration depth is shorter than the penetration depth at impact instant since repelling power from ground is very strong in finishing stage of pile penetration tasks.

5. CONCLUSIONS

A high-speed real-time visual measurement system to observe pile penetration and rebound movement is proposed by adopting a high-speed line-scan camera and a specially designed mark to recognize two-dimensional motion parameters – horizontal, vertical, and rotational movement - of a pile. Movement information for vertical distance, horizontal distance and rotational angle is determined simultaneously and the information is calculated in real-time during hammering. Especially, by adopting a line-scan CCD camera whose line rate is 10 KHz, the measurement performance of dynamic characteristics of the pile at impact instant is improved dramatically and it is possible to analyze ground characteristics and material characteristics of a pile quantitatively based on the measurement data. Finally, the developed visual measurement system is applied for a real
penetration and rebound measurement system for the construction of building and bridges successfully. In real measurements, a cloud of dust and a lump of earth during hammering is troublesome obstacles when we capture images by the line-scan video camera since the dust and the lump of earth block a part of the mark and the continuous edge tracking becomes impossible sometimes. It is required to investigate a robust offline analysis method after capturing whole images during hammering.

6. REFERENCES


Video Compression Method for On-Board Systems of Construction Robots

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ABSTRACT: This paper describes the experiences relating to transmission of digital video information from an on-board video camera of inspection wall climbing robots. The decoder is modified in the proposed transmission scheme. The main difference with the conventional scheme is an interaction of the reference frame with the post-processing. If video coding and post-processing algorithms are available, proposed modifications can be implemented almost without additional expenses. According to experiments, the method can increase efficiency of existing post-processing methods up to 40% in terms of the peak signal to noise ratio improvement. It is based on general video encoding principles and does not depend on particular implementation of the video codec and on post-processing implementation. The method can be used with standard video codecs like MPEG-1 or MPEG-4, and with variety of known post-processing algorithms. The main advantages of the proposed method are implementation simplicity and possibility to increase efficiency of the on-board inspection systems of autonomous mobile construction robots.

KEYWORDS: Mobile Construction Robot, Building Inspection, Digital Video Information, Post-Processing Algorithm.

1. INTRODUCTION

Some remote controlled construction operations require transmission of digital video information, for example, information from an on-board video camera of inspection wall climbing robots (see Figure 1).

There are many available standard video-compression methods, for example MPEG-1, MPEG-2, MPEG-4, DivX, VP3, and H.264. All of them are based on Discrete Cosine Transform (DCT) and suffer from compression artifacts. The most noticeable artifacts are blocking artifacts, which can be observed as coarse squares over the image.

Several approaches exist for the reduction of blocking artifacts. The most radical solution for this problem is overlapping transformations like MDCT [Vanhoucke] or LOT [Malvar] instead of DCT. The other proposed solutions are pre-processing [Panis] or post-processing schemes. Known post-processing algorithms were not integrated with the codec introducing some loss of efficiency. Particularly, changes made by the post-processing do not propagate over the frame sequence.

Every frame is processed independently. The efficiency can be increased by means of the integration of post-processing algorithms into the coding loop. The decoder is modified in the proposed scheme. The main difference with the conventional scheme is an interaction of the reference frame with the post-processing. If video coding and post-processing algorithms are available, proposed modifications can be implemented almost without additional expenses. According to experiments, the method can increase efficiency of existing post-processing methods up to 40% in terms of the peak signal to noise ratio improvement. It is based on general video encoding principles and does not depend on particular implementation of the video codec and on post-processing implementation. The method can be used with standard video codecs like MPEG-1 or MPEG-4, and with variety of known post-processing algorithms. The main advantages of the proposed method are implementation simplicity and a possibility to increase efficiency of the on-board inspection and navigation systems of autonomous mobile construction robots.
2. VIDEO COMPRESSION METHODS

A simplified typical DCT-based video encoder scheme is shown in Figure 2. It is assumed that a previously encoded frame or “reference” exists. The frame to be encoded is divided by the square non-overlapping blocks. Encoding is performed for each block separately. The most similar region (motion vector) is searched for every block in the reference frame. The difference between the block and the most similar region transformed to DCT domain is quantized and coded.

The difference between the source frame and the previously encoded reference frame is obtained as a result of motion compensation. The difference is quantized in DCT domain. Quantized DCT coefficients of the residual and motion compensation information are transmitted to the decoder. The reference frame is obtained as a reconstruction of the encoded frame.

A simplified video decoder scheme is shown in Figure 3. The decoder scheme is a reverse of the encoder scheme. The frame is decoded according to the motion compensation and residual information. After decoding, the frame can become a reference frame. Note, that if the post-processing is used in the decoder, it must not affect the reference frame. The reference frame must be identical both in the decoder and in the encoder. For the same reason, the encoder does not use an unmodified source frame as the reference frame. The reference frame is obtained after the reconstruction of the encoded frame.

The encoded frame contains motion compensation information and quantized DCT coefficients of the residual information. The difference between the frame to be decoded and the reference frame is obtained after dequantization of DCT coefficients and inverse DCT (IDCT). The decoded frame is obtained after adding the reconstructed residual frame to the previously decoded reference frame according to motion compensation information. The post-processing step is optional and does not interfere with the decoder.

The blocking artifacts occur after encoding at low bit rates due to a coarse quantization of the DCT coefficients. Visible blocks can not be aligned along rectangular grid because of the motion compensation.

The problem of blocking artifact removal has begun to draw attention since the JPEG compression was used. The most obvious method to remove them is to smooth block boundaries by a low-pass filter [Kim], [Yang]. Since an application of the low-pass filter to the whole image causes blurring effect, the adaptive filters are used. The filter parameters can be chosen according to initial assumptions and limitations.

By the real-time video processing, computational resources plays a critical role that makes some iterative methods [Yang] unfeasible for this task. The post-processing algorithm, suggested in [Kim] becomes a part of MPEG-4 video compression standard.

3. PROPOSED METHOD

The post-processing algorithms are not integrated with the codec. It reduces application efficiency. Particularly, changes made by the post-processing do not propagate over a frame sequence. Every frame is processed independently. The efficiency can be increased by means of integration of a post-processing algorithm into the coding loop.

In the proposed scheme, the decoder should be modified as shown in Figure 4. The difference with the conventional scheme is that the reference frame interacts with the post-processing. The post-processing is performed before obtaining the reference frame.

The encoder scheme should be modified too, because the encoder must have the same reference frame as the decoder. This scheme is shown in Figure 5. The reference frame is affected by the post-processing in the encoder structure.

If video coding and post-processing algorithms are available, the proposed modifications can be done almost without additional costs. The proposed scheme is suitable for specific applications where a video compression standard compatibility is not mandatory.

The suggested post-processing scheme was implemented by the connection of MPEG-2 video codec with a proprietary post-processing algorithm. A series of experiments was performed with the test sequence of 150 frames in QSIF format. The sequence was encoded with variable bit rates using standard GOP patterns (I, P and B frames). The post processing quality was measured according to an average PSNR measure. Results show that the proposed scheme increases the post-processing efficiency. For very low bit rates PSNR, the improvement is up to 40%.

The rate-distortion curve for the proposed algorithm along with curves for the codec without post-processing and the codec with conventional post-processing are shown in figure 6. Visual comparison results of the proposed method efficiency are clear from Figures 7-9.
Figure 7 shows original uncompressed picture of the cracks in the outer wall of the panel building. Figure 8 shows the same picture with blocking artifacts after MPEG-4 compression. Figure 9 shows the picture encoded according to the proposed method. The proposed method removes blocking artifacts from the picture, without introducing blurring to significant parts of the picture. This facilitates perception of the picture by the operator, and reduces probability of incorrect identification of the construction surface quality.

4. CONCLUSIONS

The proposed method allows improving of the existing video blocking artifact removal efficiency for post-processing schemes. According to experimental results, the method can increase efficiency of the existing post-processing methods up to 40% in terms of PSNR (Peak Signal to Noise Ratio) improvement. The proposed method is based on general video encoding principles and does not depend on a particular implementation of the video codec and a post-processing implementation. The method can be used with standard video codecs, like MPEG1 or MPEG-4, and with a variety of known post-processing algorithms. The main advantage of the proposed method is implementation simplicity.

5. REFERENCES

[Vanhoucke], V. Vanhoucke, 2001, Block Artifact Cancellation in DCT Based Image Compression, Project Report, Stanford University.


Figure 1. Diagram of building inspection
1 – wall, 2 – climbing robot, 3 – video camera, 4 – on-board control unit, 5 – cable, 6 – ground-based control unit
Figure 2. Simplified DCT-based video encoder structure

Figure 3. Simplified DCT-based video decoder structure

Figure 4. Proposed video decoder structure

Figure 5. Proposed video encoder structure
Figure 6. Rate-distortion curve for codec without post-processing (PP), codec with conventional post-processing and the proposed codec.

Figure 7. Original frame

Figure 8. Frame, compressed at 0.09 bits per pixel without post-processing

Figure 9. Frame, compressed at 0.09 bits per pixel with proposed codec
Robot Assisted Wall Inspection for Improved Maintenance of High-Rise Buildings

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ABSTRACT: A robotic system is designed for the express purpose of facilitating timely maintenance of the external walls of high-rise buildings, including inspection and cleaning. This paper addresses the application of a selected method of non-destructive inspection (NDI) to assess the quality of bonding of the tile-wall in such buildings. The basis for checking with the proposed method whether there are voids in the bonding and for evaluating the approximate size and spread of voids is established. The results obtained experimentally with the use of prepared specimens and on physical walls in a university campus are presented and discussed, confirming the validity of the method proposed.

KEYWORD: High-rise buildings, Nondestructive inspection, Robotic maintenance

1. INTRODUCTION

With more and more popular use of tiles on the external walls of high-rise buildings, bonding quality degradation of tile-walls, caused by improper installation or aging, would cause potential environmental damage or fatal danger to pedestrians. For instance, a piece of tile weighing 250g may gain a momentum of 60Nm when falling from the 10th storey of a building[1]. Therefore, safety measures introduced for regular maintenance of tile-walls of tall buildings is of paramount concern.

However, characterized as troublesome, expensive and not too safe, the traditional approach of installing scaffolding or deploying manned gondolas to carry out periodic manual checking and inspection is susceptible to human fatigue and inconsistency. Thus there is an urgent need for an automatic nondestructive tile-wall inspection method by which the signals obtained can be both recorded and analyzed in an objective way to improve the inspection quality. Meanwhile, with rapid advances in robotics and automation techniques, applying them to enhance the human safety and working condition of maintenance operators and facilitate fast inspection of large areas with program control is worth serious consideration.

Nondestructive methods for assessing and testing the integrity of bonded structure have been widely investigated. A large number of non-destructive inspection (NDI) cases on floors, bridges, beams, or pavements using ultrasonic detection and vibration parameter analysis have proved their practical utility[2][3][4][5]. However, considering the robotic tile-wall inspection of high-rise buildings, a common limitation of these two methodologies is that good contact between the sensor (ultrasonic transducer, vibration element, or accelerometer) and specimen must be kept with the use of a bonding liquid or a high pressure to guarantee their effective coupling, which is difficult or inconvenient to be realized at heights or on large tested areas. Avoiding the need to glue the sensor with the tested structure, the method using impact sounds[6][7][8] is selected and investigated for non-destructive monitoring of bonding quality.

A novel high-safety tile-wall inspection robotic system to service the maintenance of wall tiles is introduced in this paper. To establish the practical means of void identification and void size and spread evaluation on tile-walls of high-rise buildings, the theoretical basis and impact-sound interpretation of the NDI method are first presented. Then some experimental results on specimens and site tests are provided to verify the proposed method. Finally, some discussions on the findings and conclusions are included. The
2. BASIS OF IMPACT-SOUND DETECTION OF VOID EXISTENCE

Understanding the dynamics and resulting sound radiation by impact on solid and void-filled tile-walls is essential for the successful development of impact-sound detection techniques. One approach for analyzing the impact dynamics is to use the spring-mass model \[9\][10].

For simplicity, a two-degree-of-freedom spring-mass model (see Figure 1) is employed, consisting of one spring with \( K_f \) representing the bending stiffness of the tile-wall, another spring with \( K_c \) representing the nonlinear contact stiffness, and two bodies with \( M_2 \) and \( M_1 \) representing the effective mass of the tile-wall structure and of the impacting sphere respectively. In the impact of the two masses, the equations of dynamics of the system can be written as:

\[
M_1 \frac{d^2 x_1}{dt^2} + P = 0
\]

\[
M_2 \frac{d^2 x_2}{dt^2} + K_c x_2 - P = 0
\]

\[
P = K_c \cdot \alpha^{3/2}
\]

\[
\alpha = x_1 - x_2
\]

Considering the energy distribution in the system, the original kinetic energy of the sphere is used to deform the structure during impact. Assuming that the structure behaves quasi-statically, when the structure reaches its maximum deformation, the velocity of the sphere becomes zero and all of the initial kinetic energy will be converted to the energy stored by the deformation of the structure.

Therefore, ignoring the shear and membrane components of structure deformation, the energy balance equation can be given as

\[
E_{\text{sum}} = \frac{1}{2} M_1 v_0^2 \approx E_f + E_c = E_f + E_{c1} + E_{c2}
\]

where \( v_0 \) is the initial velocity of the sphere, the subscripts \( f \), \( c \) refer to the energy stored in the structure’s bending deformation and contact region’s indentation (\( c_f \) for sphere, and \( c_c \) for plate) respectively. Defining vibration energy loss factor \( \lambda \) as the ratio of energy transformed to flexural vibration of the plate structure during the impact, according to [11], the following expression can be obtained

\[
\lambda = \frac{E_f}{E_{\text{sum}}} = \frac{1}{16} \left( \frac{M_2 K_f}{\rho h K_f} \right)^{1/2}
\]

where \( h, \rho \) are the thickness and density of the plate respectively, and

\[
K_c = \frac{4}{3} E \cdot R^{1/2}
\]

\[
K_f = \frac{4 \pi h^3}{3 a^2} \left( \frac{E_2}{1 - v_2^2} \right)
\]

where parameters \( R \) and \( E \) are defined as

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}; \frac{1}{E} = \frac{1}{E_1} + \frac{1}{E_2}
\]

R1 and R2 are the radii of curvature of the two impacting bodies (for the case of the impact between sphere and plate, \( \frac{1}{R_1} \approx 0 \)), and \( a \) is the radius of the plate. The Young’s modulus and Poisson’s ratios of the two bodies are \( E_i, v_i \) and \( E_2, v_2 \), respectively.

To simplify the analysis, \( \lambda \) can be given as:

\[
\lambda = \frac{a}{h^2} \cdot Q_{\lambda}
\]

where \( Q_{\lambda} \) is a constant representing the properties of impacting bodies. From equation (9), it appears that the ratio of energy converted into flexural vibration is dependent on the thickness and radius of the plate. In the tile-wall structure, the thin tile layer caused by serious bonding degradation has small thickness and effective stiffness leading to much stronger flexural vibration under impact, compared to a solid tile-wall. Based on acoustics theory, the intensity of sound radiation is proportional to the vibration energy. Thus the intensity of sound excited by flexural vibration...
after the impact can be used as an indicator for the structure-integrity identification of the tile-wall. For simplicity, the sound intensity due to the plate can be written with the use of a constant \( Q_{plate} \) as

\[
I_{plate} = Q_{plate} \cdot E_f = Q_{plate} \cdot \lambda \cdot E_{sum}
\]

For energy converted to the deformation of impacting bodies, [11] shows that: the internal deformation energy distribution between two colliding bodies is in inverse proportion to the ratio of their elastic modulus. In other words,

\[
\frac{E_c}{E_{c2}} = \frac{\alpha_{sphere}}{\alpha_{plate}} = \frac{E_2}{1 - \nu_2^2} \frac{1}{1 - \nu_1^2}
\]

Hence, in the total indentation \( \alpha \) \((\alpha = \alpha_{sphere} + \alpha_{plate})\) of the contacting region, the part due to the sphere’s impact indentation \( \alpha_{sphere} \) is fixed and only determined by the materials of the impacting bodies. Then the intensity of resonant sound radiated by the sphere’s free vibration excited by impact indentation can be written as

\[
I_{sphere} = Q_{I-sphere} \cdot E_{c1} = Q_{I-sphere} \cdot (1 - \lambda) \cdot E_{sum}
\]

where \( Q_{I-sphere} \) is a constant. According to the theoretical analysis above, for a degraded tile-wall, the thin tile layer formed by a void separation will lead to the absorption of most of the kinetic energy of the sphere by the plate in flexural mode vibration. For a solid tile-wall, however, the loss of kinetic energy of the sphere is very small. In the meantime, the strength of free vibration of the sphere caused by impact indentation is also affected by the vibration energy factor \( \lambda \).

As a result, the relative intensities of sound radiation excited by the free vibration of sphere and plate can reflect the integrity of tile structure. Defining \( R_{ps} \) as the ratio of sound intensities due to the sphere and plate, we obtain

\[
R_{ps} = \frac{I_{plate}}{I_{sphere}} = Q_{const} \cdot \left( \frac{1}{1 - \lambda} - 1 \right)
\]

where \( Q_{const} \) is a constant representing the properties of plate and sphere material. Because the solid tile-wall generally has a thickness more than 20 times higher than that of the thin layer of detached tile caused by bonding degradation, the ratio of sound intensities due to the sphere and plate after impact \( R_{ps} \) will appear significantly different in the presence of poor bonding. Using this impact sound method, the need to use coupling agents or apply a high pressure on tile-walls can be avoided.

3. BASIS OF DETECTION OF SIZE AND SPREAD OF VOIDS

3.1 Relationship between void size and fundamental frequency

For the sake of convenience, a void-filled tile wall is modeled as a thin rectangular plate with simply supported edges. Accord to vibration principles, the flexural vibration frequency of different modes can be written as

\[
f_{mn} = 0.453c_1 h \left( \frac{m+1}{L_x} \right)^2 + \left( \frac{n+1}{L_y} \right)^2 \]

where \( m \) and \( n \) are integers (beginning with zero). From equation (15), the analytical expression for the fundamental frequency of flexural vibration of a thin plate is

\[
f_{0,0} = 0.453c_1 h \left( \frac{1}{L_x} \right)^2 + \left( \frac{1}{L_y} \right)^2
\]

Conclusion can be drawn that the fundamental frequency of flexural resonance will increase with diminishing void dimension if the thickness is the same. In addition, the shape of the void also has a significant influence on the fundamental frequency.

3.2 Void spread analysis

Figure 2. FE analysis of impact positions
Due to the difficulties in theoretical analysis of the relationship between sound radiation and impact position of void, finite element (FE) analyses (see figure 2) are performed to investigate the evaluation of void spread. With the commercial package ANSYS 56, a harmonic analysis of a thin circular plate (with a diameter of 160mm, thickness of 7mm) impacted at different positions above a circular void is conducted. The assumed parameters of concrete are input in the FE model in order to simulate the tile-wall case. Results from FE numerical studies are presented as figure 2 in terms of the normalized spectra for 9 different impacts at points along a plate diameter. It is shown that the relative intensity of the fundamental component will become stronger with the impact location getting nearer to the center of the void.

4. BASIC ROBOT STRUCTURE AND NDT SET-UP

4.1 Basic robot structure

The tile-wall inspection robotic system consists of three parts (see figure 3): robot module equipped with a nondestructive-testing (NDT) device for inspection, ground platform providing cable drive and counter-weight and supporting structure at the building roof. By design, the robotic system facilitates scanning of the entire wall by the NDT tool on high-rise buildings and is easy to install.

4.2 Set-up for NDT experiments

The NDT experimental system is illustrated in figure 4. The apparatus adopted includes: a steel sphere of diameter 23mm triggered by a coil; pre-amplifier module; AD card; microphone. The main advantage of this method is that the impacting device and microphone need not be coupled through the surface of the wall. This is of great convenience for the robot system working at heights. Moreover, it will take less time and effort to perform inspection on large-area tile-walls. For better comparison, concrete specimens and physical tile-walls in the university campus with different voids and tile types are used as test cases.

5. EXPERIMENTAL RESULTS BASED ON SPECIMEN AND SITE TESTING

5.1 Impact sounds and bonding degradation

From the analysis above, the ratio of sound intensities due to the plate and sphere after impact defined as \( R_{ps} \) may be used as an indicator to identify the bonding degradation of tile-walls in the NATURAL project. Because of the mixing of sounds from plate and sphere in time domain, \( R_{ps} \) is calculated in frequency domain by measuring the areas under the power-spectral-density (PSD) curve of corresponding bands. Shown in figure 5 is the site-test result on a physical tile-wall which can be consistently explained with the previous analysis. Values of \( R_{ps} \) on void positions are much larger than those on solid positions.
Figure 5. Sound intensity ratio \( R_{ps} \) of corresponding voids

Fluctuations of ratio values in figure 5 are caused by various factors such as the directivity\(^{[13]}\) (ignored in previous analysis) of sound-radiation fields, different impacting positions, saturation effects of microphone and background noise. Meanwhile, it should be noted that the variation of \( R_{ps} \) is a continuous curve when the impact takes place from solid to void positions. Therefore, suitable judgement should be made to ensure realistic recognition.

5.2. Impact sounds and void size

The analysis in 3.1 provides the theoretical feasibility to estimate the void size of the thin plate (with a void underneath) on the basis of the fundamental frequency of flexural vibration. The differences between solid and degraded (with various void sizes) tile-wall surfaces are verified by impact sounds obtained from specimens and tile-wall site tests (see figure.6-10 for representative results.)

In the figures, a stable spectral peak at about 6.7 kHz is created by the free vibration of the steel sphere. The resonance frequency components below this peak come from flexural mode vibration of void-filled tile structure. As seen from figure 7 to figure 10, with decreasing void dimension, the measured fundamental frequency increases from about 300Hz to 2.3kHz, 2.9kHz and 4.0kHz.
Figure 11. Theoretical and measured fundamental frequency for cases with different void sizes

For comparison, the measured and theoretical (with assumed parameters) fundamental frequencies for 7 cases with different void sizes in the specimens and site tests are plotted in figure 11. The experimental results obtained confirm the general validity of the theoretical analysis above. Because the aim of void-size evaluation is just to provide a coarse reference for the maintenance planner or operator, high precision is not required.

5.3 Impact sounds and void spread

With the help of a specially designed specimen, sounds excited by impacts at positions located from one side to another of a rectangular void (void size: 240mm×190mm) are recorded and analyzed. As shown in figure 12, the fundamental flexural vibration component becomes apparently stronger when the impacting position moves close to the void centre. Impacts near the edge of the void create sounds with weak fundamental frequency. This agrees well with the trend obtained by FE analysis in 3.2 and the information is useful for void spread evaluation.

6. CONCLUSION

To be used for high-rise building’s robotic tile-wall health monitoring, an NDT method employing impact sounds is developed in the NATURAL project. The model of impact-sound radiation is set up to offer a basis for the signal interpretation. It leads to the conclusion that: the bonding quality of tile-walls will be reflected by the relative intensities of different resonance components, and the fundamental frequency of flexural resonance provides an acceptable indicator to estimate the size and spread of voids. Different specimen and site tests presented show general agreement with the theoretical analysis. The effectiveness of the proposed NDI method is hence demonstrated. Future work will be focused on the performance improvement of void inspection and feature evaluation through further investigation on directivity of sound-radiation field and impact positions.

7. ACKNOWLEDGEMENT

The authors are grateful for the funding of an RGC grant of the Hong Kong SAR (9040711, CityU) in support of the NATURAL project.
8. REFERENCES


[7]. Jiing Iih Lai, Kung-Fu Young, Dynamics of graphite/epoxy composite under delamination fracture and environmental effects, Composite Structure, vol 30, 1995, p25-32


[10]. T. Lorriot, Specimen loading determined by displacement measurement in instrumented Charpy impact test, Engineering fracture mechanics, Vol. 65, 2000, pp703-713


[12]. Thomas D. Rossing, Neville H. Fletcher, Principles of vibration and sound, Springer-Verlag, New York, 1994

Development of an Inspection System for Cracks on the Lining of Concrete Tunnels

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ABSTRACT: Over the last several decades, many concrete tunnels have been constructed on roads, highways, and railways. For safety in concrete tunnels, periodic inspections have been conducted using nondestructive testing technologies and techniques. However, non-destructive test cannot replace the visual inspection due to their slow and complicated procedures. For this reason, they have been limited to precision inspections. The visual means also need time and there may be subjective in the measured crack data. Here, this study proposes inspection system for fast measuring cracks in tunnel lining and providing objective crack data for safety assessment. The system consists of both image data acquisition system and analysis system. The acquisition system takes images with CCD line-scan cameras. The analysis system extracts crack information from the acquired images using image processing. Measured crack information is crack thickness, length, and orientation. To improve the accuracy of crack recognition, the geometric properties and patterns of cracks in concrete structure should be applied to image processing. This proposed system was verified through a series of experiments in both laboratory and field environment - subway tunnel.

KEYWORDS: Crack, Inspection System, Tunnel Lining, Tunnel Safety.

1. INTRODUCTION

A considerable amount of tunneling activity has been going on in the last few decades. Concerns have been directed towards the safety of tunnels. For safety in concrete tunnels, periodic inspections have been conducted using nondestructive testing technologies and techniques. However, non-destructive test cannot replace the visual inspection due to their slow and complicated procedures. For this reason, they have been limited to precision inspections [1]. In the first stage of inspection, cracks in concrete structure are usually measured by inspectors who observe cracks with their naked eyes and record them while walking along the structure. As such, the main disadvantage of visual inspection is the impossibility of making a fast and sure survey. Therefore, varied studies and developments of automatic crack inspections using image processing have been made in areas including roads, bridges, fatalities, and sewer-pipes [2]-[5]. The Japanese corporation Komatsu Engineering has developed and commercialized an image acquisition system that can acquire the images of road and tunnel lining by using a laser-scanning device [6]. The Railway Technical Research Institute in Japan developed an image acquisition system of railway tunnel lining by using line CCD cameras. This system consists of five sets of line sensor camera heads, image record devices, light fittings, expansion-packing device, and tachometer-generator to acquire image of the whole inner wall of the railway tunnel [7]. Those systems are useful to collect data of crack, leakage, efflor, scale, and spall but only by using the image acquisition, and not the automatic defect detection. The algorithm for crack detection and measurement is going to be studied for fully automatic inspection system. Hence it is necessary to develop the automatic crack detection and measurement algorithm for the fast inspection and the objective crack data.

To inspect the surface of structure, it is widely used to image the surface by using camera or laser. Contrary to the efficiency enough to be used in widely varied fields, the laser-scanning device is too costly and it has a heat problem in maintaining the system. The camera-scanning device is more cost-effective than the laser device but it still has a illumination problem. From the common sense in engineering, cost is one of the most important criteria so it is required to study the image data acquisition of the surface acquired
by cameras to ensure a high level of safety of the concrete structure. Therefore the system proposed in this paper acquires images of the concrete tunnel lining with a line CCD camera, then detects cracks and picks out of the necessary items: crack length, width, and orientation. To verify the proposed system, we performed experiments inside the building, road tunnel, and subway tunnel.

2. THE SUBJECT OF INSPECTION

An itemized list of contents of the inspection for tunnel inner-wall surface contains cracks, leakage, efflorescence, scale, and spall etc. Especially, the survey on cracks is crucial for its role that evaluates the tunnel status and that determines the contents, methods, and procedures of the precision inspection [8].

The cracks are categorized into vertical, horizontal, shearing, and complex crack. The vertical crack is linear and parallel to the central line of tunnel arch. The horizontal crack is also linear, but orthogonal to the central line. The shearing crack is diagonal to the central line, and the complex crack is the combination of all the other cracks.

The proposition is 54% vertical and 27% horizontal [9]. Therefore, the proposed system is targeted to inspect vertical, horizontal, and shearing crack.

3. SYSTEM CONFIGURATION

The crack inspection system consists of image acquisition and analysis system as Figure 1.

The image acquisition system is composed of optical, mechanical, and data storage device that obtain the image of the inner face of tunnel wall to maximize the contrast distribution of crack and non-crack minimize the noise while it moves parallel to the tunnel lining. The analysis system is software that extracts, visualizes cracks, and figures out the numerical information of cracks from the image data. The information including length, width, and orientation of the crack gives a clue to judge and determine the next stage of precision inspection for tunnel safety.

4. IMAGE ACQUISITION SYSTEM

The image acquisition system is formed by the CCD camera unit, frame grabber, controlling apparatus for the field of view of camera, anti-vibration device, illuminator, encoder to measure moving velocity, and the computer for controlling the system. Figure 2. shows the image acquisition system.

CCD cameras are divided into line-scan and matrix cameras, based on their array of light sensitive device. The main advantage of matrix camera is that the camera takes images of an area only by one exposure so it is familiar with human eyes and that the interface of the camera is standardized. But, it is difficult to get the images over a large area due to the low density of sensitive device. It is hard to take a photograph with a line-scan camera because the array of light sensitive device is only one column that means for the photograph, object or camera have to move one direction but it has advantage to image the large area because of the high density of sensitive device. Therefore, the proposed system imports line-scan camera for the image acquisition sensor.
If the camera doesn’t move with constant velocity while it takes images from the surface of an object, the size of scanned-images changes in correspond to the different velocity. This change induces the dimension error when the crack information from the image data is extracted. Hence the image has to acquire a fixed rate of distance even though the velocity of the moving cart is changed. The control of line-rate on line-scan camera could be done by a feedback of measured velocity. A tachometer is used for velocity of movement. However, the line-rate of camera can be controlled by TTL level pulse with encoder.

The line-scan camera usually needs high power illuminator unlike matrix camera due to its low sensitivity. One more property that illuminator must have is the time-independent stability of irradiation. Therefore, maximum 1000W halogen light is selected for the inspection system. In addition, a reflection mirror and a scattering lens are designed for the efficiency of irradiation and equal spread of light over a large area.

Image acquisition is performed by field trials, not in a purely flat floor. The vibration caused by ununiform floor makes it difficult to extract the crack from the image data due to the out of focus of camera. Accordingly, anti-vibration caster and wire-rope are used to the system in order to reduce the vibration.

5. IMAGE DATA ANALYSIS ALGORITHM

Manual recognition of the crack requires the amount of reflected light. The crack is a portion of unsealed surface area and it reflects light less than the other area of surface. The crack and surface can be distinguished by the contrast of the light reflection. The analysis system is composed of crack detection and measurement algorithm that utilize the images derived from this pattern of reflection. Figure 3. shows the flowchart of the algorithm.

![Flowchart of crack detection and measurement algorithm.](image)

The current use of automation by image processing is limited, for the complete realization of automation is hard to achieve in the unpredictable environment. Although this study sets a goal at the complete crack detection, it is not easily obtained in effect. For example, some cracks could be wrong detected or undetected. In this case, the user intervention is needed to detect the missing crack and to delete the wrong detected crack. Therefore, the semi-automatic algorithm is realized by using a graph search method based on the two points on the crack offered by users.

5.1 Automatic crack detection

Crack detection is to distinguish cracks from the background image and is called image segmentation. If the images contain high contrast between cracks with background, the crack detection can be performed efficiently even though the illuminator is not so stable. The histogram equalization one of the most well-known a method to enhance the contrast of an image.

To extract crack information, the edge of the crack has to be extracted and the Sobel and the Laplacian operators are applied. The Sobel operator has the property of first order derivative. And the Laplasian operator has the property of second order derivative.

The Sobel operator is applied to obtain the orientation of the edge. To find the zero-crossing point from the second derivative is easier and
more efficient than to find the maximum point from the first derivative as seen in Figure 4.

![Graph of a function]

*Figure 4. 1-D edge profile of the zero-crossing*

Also, the Laplacian operator has rotation invariant property and the acquired edges are closed curve line that is an advantage of this study targeting an region composition from the crack edge. To get the stiff second derivative Gaussian filter is applied because the Laplacian is sensitive to noise.

The detected edge constructs a ravine, which is defined as a local minimum point between two edges as displayed in Figure 5(a). The 2-D image is scanned in the direction of edge as seen in (b) and the 1-D profile is acquired as in (a).

![Graph of a function](a)

*Figure 5. (a)1-D profile of ravine (b)2-D profile of ravine*

The scanning from one edge to the other is stopped when it satisfies the following conditions.

1. Cross the other edge
2. Current pixel gray-level is higher than that of edge
3. The scanned length is longer than threshold

When the scanning is stopped by condition ①, the poison of local minimum point is acquired and stored, and then the width of the crack from the minimum point to the edge is calculated. The condition ③ gives the high efficiency of calculation and the effect of noise removal because the crack is lengthy but it has problem that can not detect thick cracks which is thicker than the threshold.

The area extracted from images should be grouped according to the pattern of connection. In other words, a distinct identity between connected and disconnected sets should be endowed. A specific crack implies the set of pixel, and in this paper, the depth first search method was implemented in order to label each region.

The discontinuous image may decrease the connectivity within pixels. This further makes influence on the calculation of features by labeling differently even in the same region. To solve this problem, slopes of each end of segments are computed with certain number of pixels being modeled into a straight line, and the segments are merged if the gradient change is miniscule between the segments.

### 5.2 Crack extract via graph search

With a given start point and an end point, a graph is constructed by images and the boundary of the image is estimated through finding the least cost function. The pixels of an image are interpreted as nodes and 8-neighborhood of a pixel are connected via links in the graph, using Dijkstra method for finding shortest path [10].

1. Input all nodes from the expansion of the start node into the queue. The previous node pointer is defined as.nA. Calculate the cost of expanded nodes.
2. It is failure if the queue is empty. Output the least cost note ni from the queue and remove it. If ni = nb, back-track the previous pointer saved in each node and terminate.
3. If the condition to terminate in the process ② is not satisfied, expand the node ni and input all other following nodes into the queue. Define the previous node pointer as ni and calculate each cost of node. Go back to the process.

This algorithm always finds an optimal value. However, the number of enlarged nodes is numerous. To correct the inefficiency, a method that does not require the expansion of a node if the cost per unit length is above a certain value is used.
5.3 Crack measurement

Not all prospect crack area is derived from cracks. The causal elements include construction layer, an artificial mark, noise, or blot. This erroneous area is removed when it is assessed as non-crack through the following standards of distinguishing crack and non-crack.

① A highly small area resulted from noise.
② The area whose shape is not longish is caused by blots from water leakage.
③ A highly straight area resulted from the attachments such as construction layer or a cable.

So far crack is defined as a set of pixel. However, this definition is improper to the higher level of assessment such as safety inspection, such that an adequate use of physical quantum is required. This paper uses the quantum for the crack length, width, and the direction. The width of points comprising each area is already calculated when the region is formed from the edge. To remove the outlier among these, the width was derived as a mean value using 5 lengths of median filter. Length depends on the number of pixel. After calculating the length of diagonal as $\sqrt{2}$, and the vertical and horizontal line as 1, the real length was measured by the camera calibration. The direction of crack is determined by estimating the straight line through the principle plane.

6. EXPERIMENT SETUP AND RESULT

The experiment for evaluating the developing system was conducted in a hallway of indoor structure, a road tunnel, and a subway tunnel.

6.1 Experiment setup

In an experiment at an indoor structure, the image of the surface wall was obtained by an aluminum profile structure attached a camera pan/tilt system and an encoder on its wheel. To prevent the vibration transmitted to the camera by a disproportionate state of the floor, the flat board upholding the camera was stabilized by a wire rope. Figure 7. shows the experimental setup for indoor circumstance.

![Figure 7. Experimental setup for indoor inspection](image)

Figure 7. Experimental setup for indoor inspection

In a road tunnel, image acquisition was conducted with the indoor apparatus loaded on the truck, with the encoder attached to the tire. In the case of subway tunnel, aluminum profile structure was used in order to make the railway driving available as shown in Figure 8.

![Figure 8. Experimental setup for subway inner wall](image)

Figure 8. Experimental setup for subway inner wall

6.1 Experiment result

The image acquisition from the indoor structure was seen in Figure 9. And the crack detection was extracted as shown in Figure 10. The two vertical lines on the right of circle is groove embedded in the structure. Therefore, the highly straight line was removed, following the recognition.

![Figure 9. Image of indoor wall](image)

Figure 9. Image of indoor wall
Figure 10. Extracted crack of indoor wall

Figure 11. Image of Namsan tunnel

Figure 12. Extracted crack of Namsan tunnel

Figure 13. Image of subway inner wall

Figure 14. Extracted crack of subway inner wall

Table 1. Example of list of data

<table>
<thead>
<tr>
<th>ID</th>
<th>class</th>
<th>length</th>
<th>width</th>
<th>start X position</th>
<th>start Y position</th>
<th>end X position</th>
<th>end Y position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diag</td>
<td>66.7</td>
<td>0.3</td>
<td>6361</td>
<td>2769.4</td>
<td>6397.1</td>
<td>2754.3</td>
</tr>
<tr>
<td>2</td>
<td>Horz</td>
<td>134.2</td>
<td>0.3</td>
<td>6257</td>
<td>2956.9</td>
<td>6388.7</td>
<td>2953.1</td>
</tr>
<tr>
<td>3</td>
<td>Horz</td>
<td>132.7</td>
<td>0.3</td>
<td>6432.5</td>
<td>2960.8</td>
<td>6564.1</td>
<td>2953.1</td>
</tr>
<tr>
<td>4</td>
<td>Vert</td>
<td>190.1</td>
<td>0.4</td>
<td>7214.6</td>
<td>2859</td>
<td>7197.5</td>
<td>3044.7</td>
</tr>
<tr>
<td>5</td>
<td>Vert</td>
<td>247.9</td>
<td>0.3</td>
<td>7128.2</td>
<td>2643.4</td>
<td>7227.2</td>
<td>2866.7</td>
</tr>
</tbody>
</table>

The crack orientation displays vertical, horizontal, and diagonal crack, using length, width, the start point and the end point.

The crack inspection system proposed in this paper, although the state of surrounding environment is not negligible, has overall error rates of 70~80% and the measuring error of recognized crack is 10% or less.

7. CONCLUSIONS

This paper proposed an inspection system using an image process, which can be a solution to the problems of crack detection in tunnel lining – inaccuracy, slow rate, subjectivity, and the inefficiency in managing data. Also, the system ensures the validity and possibility based on the experiment in the indoor structure, road tunnel, and subway tunnel. However, an erroneous recognition of a crack as non-crack and vice versa prevails. Therefore, the system is semi-automated to get rid of wrong recognition of non-crack as crack, and to identify crack by a graph search method using the user-based input of the start-point and end-point of crack.

In order for a crack inspection system to develop into an expert system, a study on the characteristics of crack has to be proceed for complete automation. This paper would be help for further study by many researchers.

8. REFERENCES


Determining Internal Local Corrosion of Screwed Pipes Through Ultrasonic Testing

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ABSTRACT: In diagnosing air-conditioning pipe deterioration, it is especially important to inspect screwed parts because their original thickness is thinner than that of straight parts and it is comparatively easy for leakage to occur if there is local internal corrosion. Usually, a radiographic test is used, but this method requires a licensed person to carry out the inspection. We examined a method of applying an ultrasonic test for the inspection, and proposed a method for detecting internal local corrosions of screwed parts and estimating the size of corrosion with surface SH waves.

In this paper, we propose a method for detecting internal local corrosion of screwed parts of air-conditioning pipes with ultrasonic testing. The objective of the first step is to detect artificial corrosion and estimate its size and position. It is impossible to detect corrosion with a normal probe because a joint or valve overlapping the screwed pipe prevents ultrasonic waves from reaching the inside. Therefore, we used an angle probe, specifically a surface SH wave angle probe, because the thickness of the pipes requires a large angle of incidence, close to a right angle. We describe the following in this paper:

・ The results of experimental analysis on the echo from screwed parts of pipes.
・ The method used to detect local corrosion and estimate the size and position by using the pipe-end echo.
・ The results of tests on artificial corrosion pipes and the limitations of this method.

KEYWORDS: Surface SH Wave, Screwed Part of Pipes, Ultrasonic Test, Estimation of Corrosion States

1. INTRODUCTION

Pipe deterioration that accompanies aging of air-conditioning equipment causes many problems in buildings, particularly water leakage due to internal pipe corrosion. Therefore, it is very important to inspect for internal corrosion of pipes. Many automatic inspection systems using non-destructive testing have been developed in order to inspect quantitatively without involving difficult work or shutting down plant operations.1,2 We have also been developing a pipe inspection robot with ultrasonic testing and an ultrasonic data analyzing method.3,4 It is especially important to inspect the screwed parts of a steel pipe because it is comparatively easy for leakage to occur if there is internal local corrosions.

Radiographic testing is generally used to inspect the parts, but this method requires that a licensed person conduct the inspection. Therefore, we attempted to develop a technique using an ultrasonic angle probe. Although there are some studies on inspecting screwed parts by ultrasonic testing,5,6 there have no such studies regarding pipes. We used a surface SH wave angle probe because the thinness of the
pipes requires a large angle of incidence\(^7\). In this report, we show the results of analysis of the surface SH echo from the screwed parts, the method used to detect local corrosion and estimate its size using the echo from the end of the pipe (hereinafter pipe-end echo), and the method used to estimate its position using a simple numerical model. We show the usefulness and the limitations of this method experimentally using artificial corrosion pipes.

2. ANALYSIS RESULTS OF ECHOES

2.1 Surface SH Echo

Ultrasonic pulse waves cannot spread to the male screwed pipe if a normal incidence probe is used from outside of the pipe joint, as shown in figure 1, due to sealant and an air-layer that differs in the amount of acoustic impedance in male and female screwed parts. Therefore, we considered a method using an angle probe. We decided to use a surface SH probe because the thinness of air-conditioning pipes requires a large angle of incidence, close to a right angle. We used a probe with a ceramic oscillator 10 \(\times\) 5 mm and 5 MHz frequency. The range of direction is shown in figure 2.

Figure 3 and 4 show examples of the echoes that were measured by the probe. Measurements were taken at several points of a pipe 60.5 mm in diameter, and the distance from the screw was fixed. In these figures, the echoes from 0 to 10 \(\mu\)sec are transmitted wave and surface echoes, and the echoes from the screwed part appear at about 27 \(\mu\)sec. The peak at about 47 \(\mu\)sec is the pipe-end echo. In spite of no internal corosions, the echoes differ at each position.

2.2 Measuring Conditions

We experimentally investigated the reason why echoes from the screw differ depending on the circumferential position of the pipe. In the following experiments, the diameter of the pipe is a uniform 60.5 mm, the distance between the tip and the incident point of the probe is 8 mm, and the distance between the tip of the probe and the near edge of the screw is a constant 24 mm. The velocity of the SH wave is approximately 3,230 m/s in steel (see figure 5).

The objective of this inspection is to detect internal corrosion, so it is desirable to reduce the influences of SH waves propagating near the surface of the pipe. Therefore, we applied couplant to the surface of the pipe from the probe tip to the screw edge.\(^8\)
### Table 1 Surface Effect

<table>
<thead>
<tr>
<th></th>
<th>Maximum Amplitude</th>
<th>Minimum Amplitude</th>
<th>Average Amplitude</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.77</td>
<td>2.55</td>
<td>2.64</td>
<td>0.10</td>
</tr>
<tr>
<td>B</td>
<td>2.83</td>
<td>2.05</td>
<td>2.46</td>
<td>0.46</td>
</tr>
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</table>

2.3 Experimental Analysis

First, we observed pipe-end echoes by placing the probe on two non-screwed steel pipes (labelled “A” and “B”), and measuring their amplitude. A was made of round steel with boring and both surfaces (interior and exterior) were finished to 6.3 s. B was a standardized carbon steel pipe and only the exterior was finished to 6.3 s. We observed the echoes at five points on each pipe three times per point and calculated the average amplitude. The results are shown in table 1. Scattering of B is larger than that of A and the standard deviation of B is 4.6 times that of A. Consequently, the condition of the interior surface has a large effect on the amplitude of the echo.

Next, we observed echoes on the following objects, at either three or four points on each one. The measuring conditions were the same as before.

(a) A screwed round steel
(b) A screwed pipe made of round steel with boring, 3.8 mm thick
(c) A pipe made of round steel with boring and manufactured concentric threads having the same section as the standard cone screw and a thickness of 3.8 mm

The pipe surfaces, both interior and exterior, were finished to 6.3 s. Echoes are shown in figure 6-8. For (a) (shown in figure 6), only echoes propagating near the exterior surface are observed. All four data sets have similar peaks observed in intervals of threads. But for (b) (shown in figure 7), the three data sets are different from one another. In this case, there are echoes reflecting at the interior surface. In addition, for (c) (shown in figure 8), all four data sets are very similar to one another although there are the internal reflecting waves. In this case, all axial sections are similar because the threads are concentric, not spiral. Therefore, we can consider that echoes reflected at the interior surface and the spiral of the screw cause the difference among the echoes depending on the probe position.

3. HOW TO ESTIMATE CORROSION

3.1 Corrosion Size

In this report, the objective is to detect artificial local corrosion, which is a drill hole having a flat top, manufactured inside the screwed part of a pipe. We propose a method for estimating the size of corrosion (diameter of the hole) using the fact that the amplitude of the pipe-end echo in screwed pipes changes according to the probe position by scanning in the circumferential direction.

Three kinds of artificial corrosion, 3.0, 5.0 and 7.0 mm in diameter, were manufactured inside the screwed pipes at a uniform depth of 1.0 mm.
As shown in figure 9, we observed the echoes and measured the amplitude of the pipe-end echo with a surface SH probe. We defined the center of the corrosion as the origin for observation and moved the probe to 10 mm in both directions at 1.0 mm intervals.

There were two corrosion positions; the horizontal distance from the incidence point of the probe was 37 mm and 47 mm. As table 1 indicates, the amplitude of the echo is influenced by the contact condition of the probe and the interior surface condition of the pipe, so we used three pipes for each corrosion pattern, size and position, and collected echo data three times, then calculated the average for each pipe. The diagrams positioning the average pipe-end echo amplitude are shown in figure 10 (37 mm) and figure 11 (47 mm). In these figures, “A” and “B” refer to corrosion having a diameter of 3 mm, “C” and “D” refer to 5 mm and “E” and “F” are 7 mm. As the diagrams indicate, every curved line is like a parabola. Therefore, they were approximated by a quadratic equation and each quadratic coefficient was obtained (see table 2) in order to estimate the size of the corrosion. The extent to which pipe-end echo is not observed spreads as the diameter of corrosion increases; accordingly the quadratic coefficient of the approximated curve becomes larger as the corrosion size decreases. Here, the number of data used for approximation differs depending on the corrosion size; 7 points were used in \( \phi 3 \) mm, 9 points in \( \phi 5 \) mm and 11 points in \( \phi 7 \) mm. For each corrosion size, averages of coefficients were calculated (see table 2) and proofread using the method of least squares. It is possible to estimate the diameter of corrosion by using this regression line (see figure 12).

### 3.2 Corrosion Position

Here, position means the horizontal distance between the corrosion and the probe. It can be seen that the echo data shows a common tendency for the amplitude to decrease as time passes, that is, as the distance to the reflecting source increases, in spite of differences between the observed points. Although it is very difficult to make a completely reliable numerical model, it is possible to make a simple numerical model by using only the changes in the echo amplitude. If corrosion is on the propagation pass, it can be assumed that the amplitude would change markedly at the time for that position. Therefore, it is reasonable to assume that the position can be estimated by detecting the time. We made a simple numerical model of the
echo amplitude and estimated the corrosion position by comparing it to actual envelope data.

3.2.1 Modeling of Echo Amplitude

The amplitude of echo is a function of various factors. Four of the factors, directivity, sound field, damping and reflectance, are variables. Here, we supposed that the only reflecting source is the bottom of the thread and that it is only the propagation pass that reflects on the interior surface of the pipe and the bottom of the thread, also assuming that the reflectance is constant. Directivity of this probe was measured as shown in figure 2. The sound field was expressed as a numerical model by Freedman,[9] therefore, we used his expression. The damping coefficient was measured experimentally. As shown figure 13, we made a piece of round steel that had a horizontal drill hole (φ1), measured the amplitude of the hole echo as changing distance x and calculated the damping coefficient after revising the sound field and reflectance.

The simple amplitude model of echo is shown in figure 14. Here, the horizontal axis means the distance from the incident point.

3.2.2 Method of Estimation

The point at which the pipe-end echo amplitude is the smallest of all points in the circumference measuring was the center of the corrosion. For the simple amplitude model, it is necessary to add an offset value because amplitude can change due to contact conditions and other factors. Therefore, the offset is calculated by comparing the simple amplitude model in figure 14 to the envelope data of the echo observed at the center of the corrosion. After that, the error between the envelope and model data is calculated, and the time for the corrosion position is detected as the one having the largest positive error.

4. EXPERIMENT AND CONSIDERATION

We conducted an experiment using the method described above. The object was an artificial corrosion pipe manufactured from standardized carbon steel pipe. The conditions of the experiment are shown in figure 5. Echoes were observed when moving the probe from the center of the corrosion 10 mm in both directions at 1.0 mm intervals. The size and the position of the artificial corrosion and the error of estimation are shown in tables 3 and 4. Here, the position means the horizontal distance between the incident point and the corrosion. Each type of corrosion was set up on the respective pipe.

In the estimation of size, the error for φ4 mm is larger than that for φ6 mm, it is about 2 or 3 mm. The cause of the error is the comparatively small pipe-end echo amplitude. It is clear that the changes in echo amplitude in figure 15 and 16 are smaller than those in figure 10 or 11, which are data for proofreading; therefore, the size of corrosions is estimated larger than the real value. There is a limited ability to estimate size using this method because the amplitude varies depending on the pipe.

Therefore, it is necessary to analyze the relation between the screwed part of the pipe and the echoes in more detail. However, the method is sufficient for practical use because it is possible to safely detect and estimate corrosion by proofreading with appropriate data, having

<table>
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<th>Table 3 Estimation Results of Size</th>
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<tr>
<td>Size</td>
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<tr>
<td>φ4</td>
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<tr>
<td>φ6</td>
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<th>Table 4 Estimation Results of Position</th>
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<tr>
<td>Estimation</td>
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<tr>
<td>Error</td>
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comparatively large changes, selected from multiple pipes. The position can be estimated with sufficient accuracy for practical use, the error is less than ±2 mm.

5. CONCLUSION

We attempted to estimate artificial internal corruptions of male screwed parts of pipes with a surface SH probe in order to conduct an inspection in air conditioning plants with ultrasonic testing. In this paper, we described the following:

(1) The results of experimental analysis on the echo from screwed parts of pipes.

(2) The method used to estimate the size of corrosion by using the change in pipe-end echo amplitude.

(3) The method used to estimate the position of corrosion by comparing the envelope measuring data to the simple numerical echo amplitude model.

Using this method, we were able to detect local corrosion with certainty and estimate the position with sufficient accuracy for practical use. However, it is necessary to analyze the relation between screwed parts of pipes and the echoes in more detail in order to improve the accuracy of estimating the size of local corrosion.

6. REFERENCES


ABSTRACT: With funding from the NorthEast Gas Association (NGA), the U.S. Department of Energy (DoE) and NASA, Carnegie Mellon University (CMU) has developed Explorer, a long range, un-tethered, modular inspection robot for the visual inspection of 6” and 8” natural gas distribution system pipelines. The robot can be launched into the pipeline under live conditions utilizing a commercial no-blow system via a specially designed attachment, and can negotiate diameter changes, 45-deg and 90-deg bends and tees, as well as inclined and vertical pieces of the piping network. The modular design of the system allows it to be expanded in the near future to include additional inspection and/or repair tools. The range of the robot is an order of magnitude higher than present state-of-the-art inspection systems and is expected to fundamentally alter the way gas utilities maintain and manage their systems. A prototype system has been built, and is undergoing extensive laboratory system testing prior to scheduled field demonstrations, expected for the summer and fall of 2003. This paper will describe the overall engineering design and functionality of the design, as well as present preliminary laboratory testing demonstration (a video of the system in operation will be shown at the conference).

KEYWORDS: gas pipeline, robot, inspection, wireless, untethered, segmented, modular, live operation.

1. BACKGROUND

US gas companies spend over $300 million annually detecting and repairing gas leaks in the urban and suburban distribution network settings. The current approach is one of above-ground leak detection and pinpointing, followed by excavation, repair and restoration. The major cost incurred is typically that of digging and restoring the excavation site. A tool capable of providing real-time and long-term inspection capabilities that would allow for rapid and pre-planned inspections and repairs wherever needed, would allow utilities to better manage and allocate their operating and repair budgets, potentially reducing costly emergency repairs.

2. STATE OF THE ART

In the area of in-pipe inspection systems, there are many examples of prior-art robotic systems for use in underground piping (transmission-pipeline pigs excluded). Most of them however are focussed on water- and sewer-lines, and meant for inspection, repair and rehabilitation (Pearpoint, Beaver, KA-TE, etc.). As such, they are mostly tethered, utilizing cameras and specialized tooling, etc. (see Figure 1).

Three of the more notable exceptions are the autonomous Kurt I system from GMD (Germany) used for sewer monitoring (not commercial nor hardened), the (albeit tethered) cast-iron pipe joint-sealing robot (CISBOT; developed by Enbridge & Consolidated Edison of NY), which is deployed through a bolt-on fitting and injects anaerobic sealant into the leaking jute-stuffed joint, and GRISLEE (developed by the Gas Technology Institute, CMU & Maurer...
Technology, Inc.), a coiled-tubing tether deployed inspection, marking and in-situ spot-repair system. These systems are shown in Figure 2:

**Figure 2 : Tethered gasmain (CISBOT - right; GRISLEE - bottom) and untethered autonomous (Kurt I) robots developed to date by industry and universities**

### 3. SYSTEM OVERVIEW

In order to explore this possibility, NYSEARCH, the research committee of the NGA, DoE (current) and NASA (past), are funding a program at Carnegie Mellon University’s (CMU) Robotics Institute (RI) to develop an advanced remote and robotic inspection system, capable of multi-mile long-duration travel inside live gas mains for in-situ assessment. Under this program, CMU has developed Explorer, a real-time remotely controllable, modular visual inspection robot system for the in-situ inspection and imaging of live 6- and 8-inch diameter distribution gas-mains (see Figure 3 for an image of the prototype in a test network setting). Explorer is capable of locomoting through straight pipe segments and sharp bends, elbows, Ys and Ts, using a combination of its on-board driving-arms and steering-joints. The system is sealed and purged (and thus can safely operate in natural gas environments) and capable of negotiating wet and partially-filled (water, mud, etc.) pipes.

**Figure 3 : Explorer - Pipe Inspection System**

The architecture of the robot is simple and symmetric. A 7-element articulated body-design houses a mirror-image arrangement of locomotion, battery-, support and computing electronics in purged and pressurized housings (see Figure 4). Each module is connected to the next through an articulated joint; the joints connecting the locomotor-module(s) to the rest of the ‘train’, are pitch-roll joints, while the remaining (four) joints are only pitch-joints. This allows the locomotor-modules to articulate in any direction, with subsequent rotation-plane alignment of the remaining joints to enact a turn in any plane. The system is capable of multi-mile travel inside pipes using custom on-board battery-packs, which can use any desired chemistry depending on desired range and cost.

**Figure 4 : Overall modular layout of Explorer**

The locomotor-module contains the forward-looking mini fish-eye camera, -lens and -lighting elements, as well as dual drive actuators. These actuators allow for the deployment/retraction of a set of three ‘arms’, at the end of which are a set of custom-molded wheels used for pulling/pushing the train through the pipe; sustained speeds of up to 4 in/sec. are achievable (see Figure 5).
The battery-module(s) contain custom battery packs to allow for a full 10-hour mission with all systems consuming maximum power. This module is the only one that is pressure-sealed due to battery-chemistry concerns at elevated methane pressures (see Figure 6).

The support modules also have extendable ‘arms’, with the principle behind self-centering being identical to that of the drive-module, further easing turning and launching. The wheels at the end of the arms are passive and have embedded magnets with hall-effect encoding, allowing the system to determine position via dead-reckoning, note that there are 3 wheels per support-module and 2 support modules, allowing for averaging out errors over distance - see Figure 7 for detail:

Articulation of all modules occurs through an innovative roll-pitch joint arrangement. On the inside edge of each of the drive modules are two roll joints that allow the whole train to rotate about its longitudinal axis. Each dually-interconnected module has an active pitch-joint, enabling successive joints to be rotated to allow the joints to rotate in a plane controlled by the orientation set by the roll-actuators; this is the approach used to make turns in pipes, given that cork-screwing for non-gravity locomotors is a given fact of free-moving braced locomotors in pipes (Figure 9 shows the combined roll/pitch joint prototype hardware).
The overall electronics architecture, shown in Figure 10, depicts the on-board scheme of using a central high-MIPS low-power CPU to communicate with a set of I2C-connected microprocessors to achieve all control, data-gathering and I/O functions over a customized wireless ethernet backbone implementation. A custom-developed 32-bit lowpower central processor controls all the locomotion and steering functions based on real-time operator control commands. All on-board functions are served through a network of distributed 8-bit microprocessors communicating over an internal I2C-bus. Real-time external communications is through a wireless 802.11b implementation of UDP, using the pipe as a waveguide for long-range communications.

The imaging hardware setup is based on a digital CMOS imager (640 x 480), coupled with a miniature fisheye lens illuminated by a set of 36 PWM white near & far focussed LEDs, delivering frame-rate imagery over an LVDS interface to the main CPU, allowing it to be broadcast wirelessly - the prototype setup is shown in Figure 12:

4. DEPLOYMENT

The system is launched through a live installed vertical launch-chamber (see Figure 15), after a hole has been dug in a ‘low-cost’ location selected by the utility, where custom antennas are used to link the operator console to the robot. An operator controls the robot using a simple forward/reverse joystick interface,
while the on-board computers generate all the individual joint-steer and driving commands (see Figure 14). Turns are possible by positioning the robot at the proper place in the pipe, identifying the direction of the turn on the touchscreen monitor, and engaging an automated scripted routine to coordinate the turning and driving motions to allow for a turn through a nonstraight section of pipe.

5. PRELIMINARY EXPERIMENTS

The project team is currently experimenting with all the different types of ‘obstacles’ (bends, Ts, Ys, elbows, verticals, etc.) to be encountered in the field, in a separate laboratory pipe mock-up setting shown in Figure 15:

The access-method being used revolves around a vertical launch, using commercially-available fittings and valving, with a custom-developed pressurized and actuated launch-chamber. This method minimizes excavation costs and makes maximum use of existing OEM products the gas utilities are comfortable with in every day use. The launch-chamber and the robot shown in mid-launch (pipe removed for clarity), are shown in Figure 16:
Results to date have shown that the system can drive at 4 inches/sec. as required, with a typical obstacle-handling time of 10 to 15 minutes per occurrence. Launching has been timed at 45 minutes, with vertical pipe-climbing and retrieval still having to be tested.

6. CONCLUSIONS

The development of a segmented and modular robot train to navigate almost all types of pipe-internal geometries has been shown to be feasible. Challenges remain in the areas of power-density and communications bandwidth to maximize the profitability of such a system in commercial applications. As part of commercialization it will be critical to tailor the early prototype(s) development to a subset of inspection tasks so as to ensure successful deployment and overcome the typical early-adopter reluctance to field unknown and limited track-record systems.

7. FUTURE PLANS

Challenges remain in the area of computer-executed script development, as well as simplified user interface development to allow operators to readily and easily control the robot around obstacles and out-of and into the launch chamber. Said work is in progress and is expected to be completed by the late fall of 2003, including endurance testing in the outdoor pipenetwork specifically built for the purposes of this effort at CMU (Figure 13). Live gas main field-trials are scheduled for the 2003 pre-winter season in New York State. Patents are pending, with licensing completed and commercialization efforts well underway.

8. ACKNOWLEDGEMENTS

We wish to acknowledge the support of NASA (Contract # NCC5-223), NYSEARCH/NGA (Contract # M2000-004) and DoE (prime-contract with NYSEARCH/NGA) for the development of the Explorer system at CMU.

9. REFERENCES

The Application of Personal Digital Assistants as Mobile Computing Device on Construction Site

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ABSTRACT: Construction managers need to access the real construction site to manage the construction project. They have recently handled various types of digital information such as drawings, specification, checklists and daily reports. They usually use sheets of paper and/or field notes. As a result, a gap in time and space between the outdoor construction site and the office, which leads to the low efficiency, occurs. This paper reports the application of PDA (Personal Digital Assistants) as mobile computing device for construction managers on construction sites. First, this paper describes the aim and the essential element of the mobile systems. This also shows the analysis of necessary functions as mobile computing device through the discussion with construction managers, and the concept of development of this computer-aided engineering system. Secondly, this paper describes the outline of below subsystems with PDA: Progress Monitoring System, Inspection System and Position Check System. Subsystems have two programs: the data input program in PDA and the output program in PC. Finally, this paper indicates the development of more refined process of construction management with the mobile computing device on construction site.

- Progress Monitoring System has been built for construction managers to monitor the progress of works. This is especially useful for apartment building projects because of the large number of rooms. Construction managers can share the current progress of all rooms soon.
- Inspection System has been built for construction managers to inspect the result of construction. PDA displays the code and/or checklists each building element and work. They plot the position of unacceptable on a drawing and select related items from the lists in PDA. The output program of the system in PC can print the instruction document for subcontractors to correct improper workmanship.
- Position Check System has been built for construction managers to check the position of steel members in the structural steel erection. The output program of the system in PC can show the actual form of steel frame considering the fabric distortion graphically and the scatter of accuracy of steel erection with graph.

KEYWORDS: mobile computer, personal digital assistants, input and output device, construction site, inspection, monitoring.

1. INTRODUCTION

Various kinds of mobile device has been adopted to field jobs on construction sites. In the case of Japan, the bar-code system had been used as the data input device in the late 1980s. The electric pocketbook was commercialized in 1987 and had been used as mobile device in the early 1990s. The laptop PC has been used too. The systems developed by general contractors in this period are the prototype of the current mobile systems in construction industry. During the mid of 1990s, some computer manufactures have produced handheld PC and palm-size PC. Their function has advanced year after year. The current PDA, which is a current palm-size PC, can handle the various types of data including not only texts but also drawings and pictures. The processing speed of PDA has also developed.

On the other hand, office automation from the early 1990s improves the productivity of office works. However, construction managers still have a lot of typical and routine jobs in construction site, such as the collection of construction data and the inspection. Authors think that current mobile computers can improve the system of field work of construction managers and enhance the total productivity of construction management.
2. MOBILE COMPUTING SYSTEM

2.1 What does the mobile computing change?

Construction managers usually need to access the outdoor construction site. PC is an essential tool in construction management today. However, the current PC is not suitable for the outdoor use. They usually use sheets of paper and/or field notes for outdoor jobs. As a result, a gap in time and space between the outdoor construction site and the indoor office occurs. This gap can cause the duplex, lack and confusion of data. Mobile Computing System can function to eliminate this gap. Digital data input with the mobile system will be used quickly and effectively. Computer-aided engineering tools linked with the mobile system support construction management. As a result, the total system will realize the labor saving and the rationalization. As each job in construction is strictly scheduled, construction manager must make decision within time. Free float by the labor saving will generate the full thinking time for construction managers.

2.2 What is necessary for the mobile computing of construction management?

Construction is usually outdoor. Authors arranged the necessary functions for the mobile computing system and its devices through the interview and discussion with construction managers.

- Mobility of Hardware: Construction managers want the pocket size of hardware.
- Durability of Hardware: The strength for the physical shock, the rain, the wet and the dust is necessary for hardware.
- Compatibility of Hardware and OS: It is suitable that the system can work on any hardware and any OS (Operating System).
- Compatibility of Data between Mobile and PC: Construction managers want to use the data in PC on the mobile device. The converse is also necessary.
- Expressivity of Display: The sufficient expressivity of drawings and pictures on the mobile both indoor and outdoor is necessary.
- Stability of System: Total stability of system including OS, memory card and other devices is necessary.
- Operability of User Interface: Construction managers want to input data with gloves. Easy user interface by pen-touch is suitable.
- Speed of Operation: Start-up, Shut-down and each calculation of the mobile system needs quick response.
- Continuous Computing Environment: The computing environment has recently changed quickly. Construction managers want continuing to use the system for a long time. The computing environment that assures the long operation of systems is necessary.
- End User Computing: Construction is usually based on a project, which has unique features and/or limitations. Construction managers need the flexibility of computing system for a project. EUC (End User Computing) has also been realized in the mobile computing. Users can build subsystems for various kinds of field jobs in construction management, considering the unique features and limitations of project.

After discussing the necessary functions as the mobile computing system and devices of construction management, authors have adopted PDA as mobile computer to deal with current assignments.

2.3 Structure of Mobile Computing System

Mobile Computing System has some subsystems that basically have two programs: the data input program in PDA and the output and analysis program in PC. Figure 1 shows the operation of two programs and data transfer between them. Operation on PDA is executed by pushing the button or selecting the item from the list with pen-touch. Users can also input the content out of the list freely. Like this, all of data is easily stored in a memory card installed to PDA. Users transfer the data from a memory card to PC in the office. Data transfer with mobile phone will be possible soon. The current system adopts spreadsheet software as database to store the data. Users can share all of the data. At the same time, users can use the system individually. Users can output various arrangement and analysis of data by the system and other computer-aided engineering systems in PC.
3. MOBILE COMPUTING SYSTEM

Figure 2 shows the cover screen of Mobile Computing System. Users select project name, and user name or inspection type such as general contractor’s inspection and supervisor’s inspection. Figure 3 shows the screen of selection of Subsystems. Current Mobile Computing System has four subsystems: Progress Monitoring System, Field Note System, Inspection System and Position Check System. The integrated system shares the necessary data effectively.

3.1 Progress Monitoring System

Progress Monitoring System is to monitor the progress of construction work. Users can set the division of work freely. The application of this system for finish work in apartment building project is more useful because finish works of multi dwellings progress at several places simultaneously.

Figure 4 shows the screen of data input of progress on PDA. For each division of progress, users input the progress information such as “no start,” “start,” and “finish.” Figure 6 is an example of the graphical expression of construction progress on PC by Progress Monitoring System. This model has three buildings and nearly 360 dwelling units.

3.2 Field Note System

Field Note System is to note various unacceptable or notifications on construction site and to make the instructions for subcontractors.

Figure 5 shows the data input screen of position of an unacceptable on PDA. Users determine the position of unacceptable and, after that, select and/or input the contents. Users can select the items from the lists, which they can make them out previously, and/or can input the contents freely on PDA. The advanced function: the character recognition enhances the actual use of PDA. The contents in this current system are roughly classified into three categories: safety management, quality management, and environmental management.

Figure 7 is an example of output of instruction for subcontractors. They usually print the output by the kinds of subcontractors.
3.3 Inspection System

Inspection System is to inspect the result of construction, especially for finish works, and to make the instructions for subcontractors. Like Field Note System, users can select the items from the lists, which they can make them out previously, and/or can input the contents freely on PDA. This is more useful for multiple dwellings because they have many dwelling units and rooms.

Figure 8 shows an example of display of one dwelling unit on PDA. This screen shows the type and room planning of the dwelling unit. When users input the data, the screen of enlarged room planning appears (See Figure 9). After pointing the position of unacceptable, they select the items from the lists and/or input the contents. Figure 10 shows an example of lists. The flow of data input of one pointing in finish work is as follows: 1) Room Name such as “living room” and “kitchen,” 2) Building Element such as “wall” and “floor,” 3) Finish Material such as “wall paper” and “carpet tile,” 4) Unacceptable Indication such as “dirt” and “crack”, and 5) Related Subcontractors such as “finishing carpentry” and “glazing work.” Users can make all contents of lists previously. They can prepare multiple patterns for the lists: Room Name and Related Sub-contractors because different dwelling units may have different kinds of rooms and multiple subcontractors may be engaged in the same work in one project. The lists: Unacceptable Indication and Related Subcontractors depend on the result of selection of Finish Material. This relation enhance the efficiency of selection of item from the list.

Figure 11 shows an example of all input data of one indication on PDA in Inspection System.

Figure 12 is an example of output of instruction for subcontractors in the inspection for finish work. It reproduces the position and contents of unacceptable and/or notifications. Users can coordinate the output by the sort function. Like Field Note System, they usually make the output by the kinds of subcontractors and the type of Inspection such as general contractor’s inspection and supervisor’s inspection.

Digital data can generate the added value. For instance, figure 13 shows the room organization of unacceptable indication in the inspection of one dwelling unit and the building element organization of the living room. The analysis will be reflected to the next planning and management.
3.4 Position Check System

Position Check System is to check and record the position of building members, especially for the steel erection, and to show the actual condition of construction graphically.

Figure 14 shows the screen of selection of steel members on PDA. This system prepares three occasions of data input of position for one steel member: “before welding,” “after welding” and “after concrete-casting.”

Figure 15 shows the screen of numerical data input of position on PDA. This system adopts the scroll bar for users on construction site to input data easily and quickly.

Position Check System can show the current condition of steel frame on PC graphically. Figure 16 is an example of actual position of steel members: columns and beams (The defects are enlarged 150 times). It also shows the numerical values: the three-dimensional position of the top of steel columns, and the expansion and contraction of steel beams.

Figure 17 shows the distribution of their positions with the histogram by three-dimension. These outputs also consist of the report of quality management for the steel erection.

It is said that the welding of steel members and the error of size of steel members are factors of the above disorder. Authors consider the establishment of feedback system of the result for the planning and management.

4. EFFECT OF MOBILE COMPUTING SYSTEM

One of aims of Mobile Computing System is the improvement of productivity of construction management. Figure 18 shows the comparison of productivities of the inspection for finish work per 30 dwelling units (The result of conventional system is a simulation based on construction manager’s experience). The job with PDA needs more time for the preparation but reduces the time of the data reduction and instruction print.

Another is the mobility of data and information in PC. General contractors in Japan are positive for sharing knowledge: the code, the checklist for various jobs and the related information. They usually arrange and store them in their own intranet from the viewpoint of knowledge management. Construction managers can bring them freely with Mobile Computing System.
5. CONCLUSIONS

This paper describes the aim and outline of Mobile Computing System. Authors examined necessary functions for the mobile system and adopted PDA as mobile computer.

The following conclusions can be drawn by establishing Mobile Computing System and analyzing various data:

- **Mobility of Information**: The mobile system can offer the information of PC in the indoor office on construction site.
- **Increase of Productivity**: The mobile system can realize the increase of productivity of construction manager. Although, preparation needs more time, the man-power of data reduction and output are decreased.
- **Link of Existing CAE tools**: Quick data input with the mobile system can realize the effective use of data with the link of existing computer-aided engineering within time. This will lead the rational decision-making by construction manager.
- **End User Computing**: End User Computing is important especially in the application of computer-aided engineering for construction management because construction projects have many unique features and limitations.

Next Generation of Mobile Computing System can be modeled as follows:

- **Digital Camera**: Digital camera has already installed the mobile computing devices. The function of attaching the information to each picture on the mobile easily is needed.
- **Speech Recognition**: The function of speech recognition has already established. The elimination of noise on construction site and the conversion from speech about construction to character are needed.
- **Real Time Data Exchange**: Various construction works on construction site proceed simultaneously. Real time recognition of construction site leads better management. The application of mobile phone including cellular phone will be possible and suitable.
- **Compatibility of Hardware and OS**: In actual, various types of mobile computer and OS exist. The compatibility will be necessary to spread the application of computer-aided engineering.
6. REFERENCES


Efficient Support for Mobile Computing on Construction Site

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ABSTRACT: Today’s information exchange in managing projects are to a great extent supported by information technology. Especially mobile computing potential can significantly improve the information exchange in construction. This paper addresses some important mobile computing potential which can help tackle project collaboration and information dissemination problems. Special attention is given to the organizational and mobility issues of construction projects which must be considered by implementing mobile computing in construction. The final objective of the paper is to show why should be further research on mobile computing more focused on identifying the weaknesses of the present project information exchange procedures and their optimisation according to the applied IT in order to employ all of its advantages. The paper, however resides on practical experiences, which have been accumulated through a series of experimental projects called e-site.

KEYWORDS: construction site, mobile computing, project communication

1. INTRODUCTION

In recent years, the emerging information technologies e.g. mobile computing have significantly affected business processes and workflows. This has been demonstrated through the increased need to access useful information at any time and any place, creating information and sharing it with colleagues. Such information access showed its high value in terms of increased productivity, reduction of costs, faster communication and improvement of working conditions. In construction, information technology is being applied slowly compared to other industry sectors. One of the reasons repeated in many papers and reports is that the construction industry has to build its products under circumstances not convenient for appropriate IT support: the fragmented nature of the construction industry [Howard], uniqueness of products, vast number of companies and actors included, etc.

On the other hand, we are faced with another paradox. Currently, many engineers are still using tools that are far from state-of-the-art, and they are very reluctant to change tools. This situation lends itself to the complexity of engineering information structures today. Existing processes could be rendered much more efficient by altering older information structures to support newer ones, and rethinking our current philosophy of computer use [Rebolj]. Despite the availability of hardware systems and high speed wireless networks, we are still lacking software systems designed to support specific on-site tasks, provide helpful guidance through these tasks, and support intelligent methods of human-computer interaction that take into account the context of on-site construction and supervision activities [Menzel].

After conducting a series of experimental projects, called e-site, we obtained a firm belief that mobile computing extended information systems, present one of the possible solutions to improve Construction Information Technology, thus providing appropriate information flow in the lifecycle of a building product.

2. POTENTIALS OF MOBILE COMPUTING IN CONSTRUCTION

The term “mobile computing” or “ubiquitous computing” has no clear definition, although some studies have already tried to survey this fast-growing area of information technology. Mobile computing does not only involve mobile computing devices (such as laptops, notebooks, PDAs and wearable computers), which are designed to be carried around, but also the mobile (which in practice means wireless) networks to which these computers are connected. Specialized
services are the third component, rounding out the
definition of mobile computing.
Although the number of research papers
addressing mobile computing is modest, there is
no doubt that a great deal of research is still going
on, perhaps even too fast for papers to be published. In the field of civil engineering,
interesting reports can be found, most of them are
specialized on a specific task: for inspection -
oriented applications [Garett], for recording
activities on a building site [Menzel K.] etc.
Two main aspects exist when looking at any
system: the partial and the holistic aspects. In
construction this aspects can be defined as
“company view” or “project view”, and “personal
view” or “actor view”. In both aspects, mobile
computing can significantly improve the
efficiency of information flows or of information
systems. Thus, we have to be aware that mobile
computing implies the following facts:
• a mobile computer is bound to a specific
  person
• the location of a mobile computer can become
  a significant piece of information
• the mobile computer (and thus the person) is
  available anytime, anywhere
• the person has access to the system anytime,
  anywhere
These facts are of utmost importance and the basis
for the core potentials of mobile computing in
construction.
From the company (or project) view any
information system in use can improve as follows:
• information system boundaries extend to the
  maximum, which means that information will
  flow to and from the destination/origin points
  without delays or obstacles
• additional information is available from
  terminal points, like their position, user ID,
  temperature etc.; in other words, terminals can
  help applications to become context sensitive
From the personal view following improvements
are significant:
• the person can be available anytime, according
to her/his role in the relevant projects
• any other actors in relevant projects are
  available
• personal communication can improve
  significantly through automatic selection using
  context parameters (date and time, location,
  activity etc.)
Based on these potentials we started to built a
concept of a personal communication network by
measure of the human – the actor – involved in
various project and tasks (Figure 1). From the
aspect of a project, this means a much smoother
flow of information and thus a higher level of
quality.

Figure 1. Personal communication links – People
can work “closer” to each other in terms of more
direct communication, organization can become
structured on a single level.

Other details of concept are outside the scope of
this article and therefore not presented. Instead
main experiences as a basis for concept gained
through a series of experimental projects called e-
site are described and demonstrated.

3. STUDY

In autumn 2000, a multipurpose experimental-
educational research project called Mobile
Computing at a Construction Site (or e-site, for
short) was launched at the Faculty of Civil
Engineering of the University of Maribor [Rebolj
D.]. The project has been conducted by the
Construction IT Centre and carried out by students
and engineers from the construction industry. The
purpose of the project has been to answer the open
questions of how mobile computing works on site,
what organizational changes are required, are the
common commercial mobile phone network
services sufficient for mobile computing in
construction, how complex is the problem of
integrating mobile computing into existing
information systems (which are still not integrated
to the desired extent themselves), and what
educational efforts will be necessary.
Simple and effective mobile document management system based on the study results has been designed and tested to demonstrate systematic use of mobile computing especially on construction site (Figure 2).

![Figure 2. Prototype of mobile document management system](image)

The system offers the following functionality: password-protected projects with multiple directories, each containing a flat set of files, every directory is linked to a list of users, each of whom has an electronic address for system messaging purposes (e-mail or mobile phone number for SMS messages), uploading and downloading files, activating software for supporting file types, alerting users to file changes in their directory (each message contains the time and type of change, and the name of the user who made the change).

The system demonstrations were performed according to the process shema of participating practice partner to directly show how the data flow could become fully automated and how to connect project members of all hierarchal levels with support of mobile computing.

The final test, carried out in 2001 (Figure 3), showed that the efficiency of information exchange in construction, between the construction participants and within the construction site itself, can be improved significantly even by using current mobile computing components: unmodified, available PDAs, mobile phones and other existing wireless networks, and web services. This project has been continued in 2002 [Magdic] and in 2003. The results proved the high potential of mobile computing for the construction industry.

![Figure 3. E-site – experimental - educational research project.](image)

3.1 Construction process optimization considerations

3.1.1 Organisational issues

The implementation of mobile computing into construction practice has demonstrated its advantages in many ways. Better information and communication flow, enhanced performance, higher productivity and other features enhance the possibilities for a successful accomplishment of project goals. On the other hand, there are several reports which elaborate on the weaknesses of the present system relations within construction sites and on the problem of poor on-site management disputes and various mistakes in design and on-site applications [Horner]. In addition, further research on organisational issues in the construction industry has revealed that construction is very unsympathetic to changes of internal organisation despite obvious environmental changes in the last few decades [Radosavljevic].

It has been shown that proper attitude towards the organisation within companies can reduce costs, increase labour productivity and hence make construction a much more profitable industry.
These were achieved by merely altering the way of managing the organisation [Radosavljevic M.]. However, the emerging experimental on-site mobile computing projects show that mobile computing represent for management an efficient tool to make internal flow of information more reliable and faster. It seems there is a two-fold information flow in construction, namely: an official flow of documents (progress reports, cash-flow reports, survey reports, daily plans, etc.) and an informal communication between different levels of management regarding work progress, quantities, cash flow and on-site problems that is often interrupted and highly hierarchy-dependent.

While regular, complicated procedures of inter-organisational submission of documents are well-accepted in construction, the well-trained eye could easily detect the disadvantages of these procedures. The documents are submitted hierarchically, irrespective of the speed of the process and they are required to follow specified paths instead of taking effective and legal shortcuts. This further discloses that to a certain degree some information is hidden from most participants, despite the necessity of fast and effective information exchange between a construction site, investors, headquarters and all others involved.

For instance, a foreman receives the information from the operative plans once already on-site, in the form of daily activity plans. With the exception of a site manager, other participants (project manager, investor, headquarters, etc.) receive information on daily activities several days or even weeks later. Similarly, foremen do not have particular instructions on whom to contact when disruptions or delays occur. This is more or less left to a foreman's personal discretion. However, in order to apply mobile computing to establish appropriate document paths, the communication possibilities need to be restricted. This restriction appears to contradict the basic purpose of mobility which is free communication. Often, a free (or informal) communication is the one that contributes to the project's success. If it is not effective, it may cause delays and disruptions and result in financial losses.

Mentioned limits should only be project-wide, enabling all participants to be permanently, actively involved (even if they are not physically available). When dealing with a specific on-site problem, foremen should be able to contact not only the site engineer but also the other partners, including designers, planning engineers, R&D specialists, the supplies department, etc. according to the nature of a problem. Implementation of mobile computing enables this kind of free communication instantly, but the question remains whether companies really aspire such a free flow of information. It is reasonable to assume companies will approve of this free communication, because it results in better performance, more satisfied clients, higher productivity and traceable responsibility.

3.2.2 Mobility issues

In current projects we are focusing on different issues of mobility. We are observing mobility from the perspective of terminals and users [Piere]. The terminal is mobile if it can be successfully located and identified when it is carried around. At the same time it should provide access to telecommunication services from different locations. User mobility is a different concept from terminal mobility. Here, the types of devices to access information are not important. Terminals can be shared among users and users can access the same services through different devices. However, it was found that customization of services has not reached an appropriate level yet. Here we have in mind broadly available and not specially designed applications. Users should be able to access the same service – application and information from different terminals and at different times. A great deal of progress needs to be made in this area. It is almost impossible for inexperienced users to change devices and access different services because of high service connection and data manipulation overhead. We see very common and simple solutions using web and HTTP and FTP protocols as highly desirable in this context. However, available services should better adapt to a variety of devices available, and thus provide better interaction with a broad user audience.

4. CONCLUSION

Within this paper the authors described how mobile computing technology might contribute to improve information exchange in construction. It may be expected that mobile computing components (mobile devices, mobile networks, mobile services) will develop quickly, thus improving efficiency of mobile computing in the construction field even further. On the other hand,
information systems supporting engineering processes will have to be redesigned and improved so as to attain a higher degree of information integration and a higher efficiency of information flow.

In this respect it is very important to have at least an organization-wide policy of mobile computing use that includes standardization of procedures and infrastructure. Implementation should inevitably include process improvement efforts.

Anyhow, it is obvious that mobile computing already play an important role in the development of construction processes.

5. ACKNOWLEDGEMENTS

We thank SCT and Vegrad for their construction sites, Teleray for the Nokia terminals, Tobo’s for the Cassiopeia PDA, SiMobil for the GPRS terminal and services, and especially Xybernaut Germany for four wearable computers with a variety of add-ons.

6. REFERENCES


Development of a Universal Position Interface, Applied for reliable and interactive access from distant locations to central database information through unambiguous position key in the construction industry. (UPIA)

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ABSTRACT: To improve the availability of reliable information on an arbitrary location in or outside a construction project and to exchange information faster, more efficient and in an interactive way HBG developed the UPIA-device. With this handheld device location based information can be generated on site and can be used interactive by reliable and interactive access to a central database on a distant location. As a tool for quality monitoring the application is tested successfully at complex building projects.

KEYWORDS: GPS, INFORMATION MANAGEMENT, LOCATION RELATED DATA, PORTABLE COMPUTERS, POSITION INTERFACE, PRODUCT MODEL DATABASE, SUPPORT SYSTEMS FOR MONITORING.

1. INTRODUCTION

One of the problems the construction industry is facing is the need and urge for availability of reliable information on an arbitrary location in or outside construction projects all over the world. Beside this there’s consensus of opinion that exchange of information should go faster, more efficient and in an interactive way to get the correct information, just in time in the right place.

In general, development and research is increasing in the area of mobile communication, developing applications for handheld computers and the use of positioning technology, for example in navigation systems by GPS. Hollandse Beton Groep (HBG) expects possibilities for optimising their processes and solutions for the described problems by introducing this technology in the company.

HBG is developing an application for the construction sector together with several European partners: Tensing SKS [NL], Tethys [NL], Becker [D], VCS [D], IMST [D], and Egemin [B] ¹. These companies are mainly involved in development and consultancy in communication and positioning in aviation and satellites and in industrial automation solutions. HBG is contributing their specific constructors’ knowledge.

This paper describes one of the promising developments regarding information and information management in the construction sector at HBG.

The next paragraphs describe what the UPIA-project involves; how it is introduced and developed on the construction site together with the building workers and what the results of the introduction of the application are.

2. UPIA

Communication conflicts, beside the increasing complexity of construction projects are causing

¹ Craft project: CRAFT-1999-70547, EC-contractnr.: IST-2000-52034
problems during construction. Delay and fail costs\(^2\) are results of for example misunderstanding and poor project insight\(^3\). From this point of view HBG participates the UPIA-project to support site monitoring activities, which require data access and storage to locations.

### 2.1 Monitoring activities during construction

During the construction process, several aspects are checked on site on a regular basis, per location. In the current process much data are manually re-entered per quality or process check. Lack of structured data, use of electronic documents, use of handheld devices and the number of design changes disturb these monitoring processes. Mobile access to location related data is expected to support the monitoring process and to eliminate these disturbing factors.

### 2.2 Data structuring, positioning and communication

Mobile access to location related data first requires data structuring. Critical aspect is that a lot of data related to locations, spaces and levels, is processed during the project.

The status quo is that data in several documents are not related and interpretable for computers, spreadsheet programmes, 2D drawings containing lines and specifications in voluminous documents. The challenge is to utilize the application in combination with model based ICT solutions. These model based solutions enable to create and process 3D product models, from which consistent drawings can be derived and which provide an intelligent object oriented data structure for storage of ‘all’ product and process related data. In this way the ‘Central Database’ is realized.

UPIA Project-partners are developing a Universal Position Interface: a GPS-based device for indoor and outdoor positioning.

Depending on the technology used for identification of a location, the need for interactive access to a central database sophisticated communication technology is required.

### 3. PROCESS OF DEVELOPMENT

To introduce this new ‘high-technology’ in what is often identified as a ‘low-tech’ sector requires a step by step development and approach of the development process. The choice was made to development an application which solved an ‘existing problem’, therefore close cooperation with building workers on site was crucial.

#### 3.1 Phase 1

A stand alone Application was developed to support quality monitoring on site per space. Rooms were identified by scanning transponders and a laptop was used as handheld device. This solution was evaluated on a live project: Hotel Mercure.

![Figure 1: Hotel Mercure a/d Amstel, Amsterdam the Netherlands](image)

The hotel was expanded with a tower building which contains 196 rooms on 18 levels. This result in regard to monitoring a number of items of 196 each was containing 33 items resulting in 6468 parameters.

The database application was considered as a very useful help, especially because of the number of items. The Laptop and the transponder scanner were considered to replaced by smaller and more useful and ergonomically hardware. Based on the experience with introducing new technology on site in the past an important result was the positive

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\(^2\) Estimated between 2.5 and 5 billion Euros in the building construction sector in the Netherlands in the year 2000. [NRC, 05-23-2003 ‘Fouten in bouw kosten miljarden’]

\(^3\) SBR, ‘De bouw moet om, op weg naar feilloos bouwen’, 2000
response of building workers and the willingness to cooperate in a next step.

3.2 Phase 2

Components were realized to enable model based ICT in combination with location identification, based on coordinate input. The component enabled to interact with future UPIA device in the next phase.

In this phase the 3D model provides the data structure and the space is identified in the same 3D model, based on given coordinates. In this stage wireless connection was tested in combination with an ASP and a tablet pc. Coordinates within several spaces were associated with the transponders.

Although the GPRS connection was poor on the highest two levels of the Hotel Mercure building the benefits of the application became clear. The number of users was reduced. Only the foreman used a pocket pc for monitoring.

3.3 Phase 3

The in phase two developed components to enable model based ICT in combination with location identification is further developed to be able to interact with UPI device for positioning.

The 3D model provides the data structure and the space is identified in the same 3D model, based on coordinates given by UPI. The test period at the Lucas Andreas Hospital in Amsterdam is, at the time of writing this article, not finished. However the first results seem very promising. The UPIA-device is successfully used as a monitoring tool, and it appears to improve the opportunity for real-time decision-making on site.

4. CONCLUSIONS AND RECOMMENDATIONS

The UPIA-device can be a useful tool for monitoring on site. Especially large and complex building projects provide lots of opportunities because of their number of to be identified items and complex relation structures between the items.

The UPIA device can possibly be improved by:

- benchmark GPRS and other wireless solutions
- implicate use of interface ASP and tablet functionalities [making notes is required, to be saved as pictures]
- GPS precision and availability indoor
5. REFERENCES


[UPIA] UPIA.org
ABSTRACT: Electronic construction information portals have become popular in recent years but most portals are intended for business transaction processing. This paper describes a web-based construction information portal (e-Portal) intended for use by construction engineers. A functional framework for the portal is presented along with a 4-Tier architecture including the Presentation Layer, Application Layer, Application Programming Interface(API) Layer, and the Database Layer. Construction related information such as legal regulations, standard specifications, technical manuals, construction materials and manufacturers is organized and presented to reflect the multiple functions of the e-Portal. With the presented e-Portal architecture, construction information can be acquired and processed via a Wireless Application Protocol (WAP), mobile devices, and WWW(World Wide Web) with the use of the Extensible Mark-up Language (XML) and Extensible Stylesheet Language (XSL)).

KEYWORDS: e-Commerce, e-Portal, 4-Tier architecture, Construction Engineering and Management

1. INTRODUCTION

IT (Information technology) infrastructure including network and hardware is now well-established in developed nations. Implementation practices in business industry are remarkable but not evolving rapidly at this time due to the slow global economy at the start of the 21st century. Electronic portal business in the construction industry has also suffered to some extent, but consortia of major construction companies have developed electronic business portals as a market place for construction materials. These portals focus mainly on buying and selling materials. In other developments, some governments around the world require electronic submission of construction related documentation for contractors involved in public projects.

Electronic networking technologies already have an established place in the engineering and business worlds, including the construction industry (Abduh and Skibniewski 2002a; 2002b). However, it is important to consider the limitations of the professional environment before a successful launch of an IT based solution can be realized (Abduh and Skibniewski 2003).

Focusing on South Korea as an example, construction information related to public projects such as drawings, specifications, and budgets must be submitted electronically to the government (MOCT 2001). However, access of electronic sources of construction information, e.g. construction laws and regulations, standard specifications and manuals, construction materials and manufacturers’ data, national performance standards, etc. is limited.

Public construction project information is part of the public domain but it has not been fully organized and made available electronically to the public. Construction engineering and management require a variety of sources of information and knowledge due to the fragmentation of construction project participants. Most publicly owned corporations in Korea have developed construction management information systems based on Computer-Aided Acquisition and Logistics Support/ Contractor Integrated Technical Information Service (CALS/CITIS) standards and the CALS Implementation plan developed in 1997. Construction management information systems are intranet systems and are only open to project participants. Thus, neither quantitative
nor qualitative information is exchangeable electronically among construction engineers in the public domain.

Career management of engineers in construction in Korea is mandatory. The Korea Construction Engineers Association (KOCEA), a public corporation founded in 1987, is currently responsible for career record management and the training of engineers in construction industry. Career management is an obligatory affair by law but training is voluntary. The primary objective of KOCEA is to supervise and manage business and services in the area of career management. There are over 1.6 million engineers and about 36,000 contractors and sub-contractors working in the Korean construction industry. Submitting official records of each engineer to project owners, including personal records of education and training and project related experience, is mandatory.

Due to the downsizing of the Korean government budget, KOCEA is now considering changes in the existing business models and pursuing profits goals from new business ventures. Eventually, the Korean government plans to transfer the management of engineering records to KOCEA. Thus, the development of new business models is imminent. Electronic portal business is considered as a new business model because a significant number of construction companies and engineers have close relationships with KOCEA.

2. ELECTRONIC ACCESS TO CONSTRUCTION INFORMATION

There is no single gateway providing access to construction information available over the Internet. Various types of electronic business portals such as e-market place, e-procurement, and e-distribution focus on business transactions related to construction materials, suppliers and manufacturers (Ryoo 2001). Project specific portals utilized by diverse project teams operate typically within an Intranet, and are off-limits to individuals and businesses not directly associated with the given project. In order to provide relevant information to engineers in the public domain, open access to construction industry information is necessary.

Contractors are now being asked by public project owners to submit all construction project documents in a pre-defined digital format so that they are accessible over the Internet by the public (MOCT 2001). Using those electronic business portals is troublesome since the information does not meet the national formatting standards. Existing information systems do not allow internet users to access intranet information systems. A web-based e-Portal can be a unique source of construction project and industry information.

A functional framework and system architecture for a construction information portal is the subject of this paper. The information portal requires a significant amount of information uploads and execution of construction programs. Current three-tier systems are designed for business management systems within similar platforms. Four-tier architecture is proposed in order to reduce the limitations in integrating construction programs and various external databases.

3. OBJECTIVES AND SCOPE

The primary task includes the development of a functional map of an e-Portal suitable for the construction industry. e-Community and e-Projects have been implemented in Phase 1 of the portal development.

Functionally, an e-Portal must meet the national CALS/CITIS standards. Thus, the following tasks are also required:

- Set up a portal compatible with existing Intranet and Internet systems
- Integrate existing web sites and their databases
- Set up a special module for the Asia Pacific Economic Cooperation (APEC) Engineers and independent contractors

In order to be able to support the engineers and contractors, the following additional considerations are included:

- A unified gateway to web sites in construction
- Allowing private and virtual workspace for contractors and engineers
- Offering continuing professional training courses over the Internet
- Offering Application Service Provider (ASP) and consultation services to contractors
- Providing information on construction industry and project information compatible with Intranets

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Considering commercial services for construction engineers in the future

Finally, the following technical aspects are also considered:

- Developing a platform-independent architecture
- Keep low maintenance costs and easy operability
- Providing function expandability and scalability

4. METHODOLOGY AND APPROACH

Functional framework and system architecture comprise six modules: “e-Community” module containing construction policy and economy, “e-Projects” containing engineering and construction project information, “e-Campus” opening virtual training opportunity, “e-Consultation” for arranging consultation among engineers and firms, “e-Engineers” for career management of enrolled domestic and overseas engineers, and “e-Mall” to create a cyber market place in the future.

Web development technology proposed by Dmind (2001) has been adopted. Dmind presented an eXtensible Mark-up Language (XML)-based platform for contents management. Four-tier architecture is considered due to various applications and legacy systems that are widely used in construction. The four tiers are “Presentation Layer” as user interface, “Application Layer” as contents manager, “Application Programming Interface (API) Layer” as a bridge between programs, and “Database Layer” as adapter to access databases. Unlike in a three-tier architecture, the Application Layer splits into two layers: Application Layer proper and API Layer. The API Layer is responsible for accessing the applications and legacy systems including their databases. Thus, integration of new systems and legacy systems is accomplished.

5. CAREER MANAGEMENT PRACTICE IN KOREA

Engineers’ career records include two types of career information: occupation and professional information. Each engineer is responsible for providing and updating his or her career information to KOCEA. Professional information includes fourteen major specialty fields, fifty-three professional divisions, thirty-one types of construction projects, and thirty-one types of job assignments. In addition, project specific information such as construction methods and specific position/title of the engineer is included.

Table 1 shows the classification index to categorize and classify engineers based on the factors listed above.

<table>
<thead>
<tr>
<th>Fields of Construction</th>
<th>Certificates and Licenses</th>
<th>Level of Expertise</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil</td>
<td>Professional Engineer</td>
<td>Expert</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Architecture</td>
<td>Engineer</td>
<td>Advanced</td>
<td>Master</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Associate Engineer</td>
<td>Intermediate</td>
<td>Bachelor</td>
</tr>
<tr>
<td>Regional Planning &amp; Development</td>
<td>Technician</td>
<td>Beginner</td>
<td>Associate-Bachelor</td>
</tr>
<tr>
<td>Safety Management</td>
<td></td>
<td></td>
<td>Diploma</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metallurgical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining &amp; Resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical &amp; Ceramic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The career management information process has been defined by KOCEA as shown in Figure 1.
The engineers are grouped and classified based on the construction specialty, possession of certificates or licenses, and levels of expertise and education. Over 480,000 of about 1.6 million engineers in Korea are listed. Table 2 shows the distribution of engineers in major construction fields.

Table 2. Construction Engineers managed by KOCEA as of December 2003.

<table>
<thead>
<tr>
<th>Fields of Construction</th>
<th>No. of Engineers</th>
<th>Fields of Construction</th>
<th>No. of Engineers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil</td>
<td>153,784</td>
<td>Metallurgical</td>
<td>1,803</td>
</tr>
<tr>
<td>Architecture</td>
<td>155,197</td>
<td>Electronic</td>
<td>3,623</td>
</tr>
<tr>
<td>Mechanical</td>
<td>50,791</td>
<td>Mining &amp; Resources</td>
<td>2,017</td>
</tr>
<tr>
<td>Regional Planning &amp; Development</td>
<td>22,429</td>
<td>Industry Application</td>
<td>320</td>
</tr>
<tr>
<td>Safety Management</td>
<td>16,962</td>
<td>Chemical &amp; Ceramic</td>
<td>779</td>
</tr>
<tr>
<td>Transportation</td>
<td>798</td>
<td>Textiles</td>
<td>45</td>
</tr>
<tr>
<td>Environmental</td>
<td>8,706</td>
<td>Miscellaneous</td>
<td>59,888</td>
</tr>
<tr>
<td>Electrical</td>
<td>6,040</td>
<td>Total</td>
<td>483,182</td>
</tr>
</tbody>
</table>

A survey was performed to investigate the use of information technology in the construction industry. Design and construction organizations in five major cities including Seoul, Busan, Daegu, Kwangju, and Daejeon have participated in the survey. Engineers in the fields of architectural engineering, construction, construction management and construction supervision in civil and building construction are included. The surveys focused on the familiarity
with information technology of the construction engineers at main offices and project sites. The following are the key factors.

- The exposure of construction engineers to information technology
- The degree of computerization of the workplace
- The accessibility of network, hardware and software environment
- The preference of construction contents
- The serviceability of existing construction portals

The survey also shows that 38% of engineers use the internet less than one hour daily and 29% of them use from two to three hours daily. 87% are able to use Asymmetric Digital Subscriber Line (ADSL) or Wide Area Network (WAN). 46% use the Internet because of easy access to it and up-to-date construction-related information available. Commercial portals are frequently used to find and download construction information by 49% of the engineers. E-mailing is second in use at 22%. Figure 2 shows the types of construction information requested by construction engineers. They are concerned with law and regulations, specifications and design guidelines, new technology, project bid announcements, construction materials and prices. It follows that a successful e-Portal should include general construction information on engineering and construction and project bids.

![Figure 2. Demand for Construction Information.](image)

5.1 e-Business Portals in Construction

Prior to 1990’s, quality was not a major concern due to development-oriented policy in the construction industry in Korea. After a series of engineering and construction failures, the government established strict regulations to improve quality, enforce safety regulations, and increase productivity of engineering and construction. As a result, KOCEA manages and certifies official career records of about 25% of construction engineers. Submitting certified career records becomes mandatory. Moreover, the domestic construction market is open to international constructors according to the agreements with the World Trade Organization (WTO) and APEC put into effect in January 1997.

There are four organizations such as the Korea Institute of Architects, Korea Professional Engineers Association, Korea Civil Engineers Association, and Korea Surveyors Association, to manage professional careers of their constituents in Korea. There is currently no unified approach to data formats and contents.

6. FUNCTIONAL FRAMEWORK AND ARCHITECTURE

The six modules of the e-Portal are shown in Figures 3 and 4. The e-Portal serves as a principal gateway to other construction portals and becomes a knowledge management system for construction professionals. Figure 5 shows the sub-functions of e-Portal developed based on the conducted
surveys and subsequent business process re-engineering.

Contents such as business process and rules, software components, data sources, and legacy applications can be managed, in addition to traditional content such as images, static HTML, documents, etc. since the definition of contents becomes wider (Dmind 2001). However, additional utility functions are needed to support the transactions of contents.

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**Figure 3. Dependency of e-Portal Modules and Users**

![Diagram showing the dependency of e-Portal modules and users.](image-url)
The 4-Tier platform uses the “Model, View and Controller” (MVC) to present information as shown in Figure 7. The MVC architecture has been used as development architecture because it simulates input-process-output model. The Model encapsulates a real world problem and formulates into a comprehensive and functionally compatible process form. The Controller interacts with the Model and the View. The Controller is a logical process of real world business processes. As described in Figure 8, templates (user interface) and their elements (utility functions) are designed, defining types of content, parsers to handle business processes, and views in order to combine templates and their content.

Using templates, pre-defined HTML pages, information can be deployed to homepages. Thus, the user interface can be modified by simply changing templates. With XML data format, information can also be deployed to different types of user interfaces such as WAP (Wireless Application Protocol), PDA (Personal Digital Assistant), and other XML. Figure 9 shows a homepage of an operating e-Portal. According to the verified membership level of a user, different levels of construction information is available. Most frequently asked information such as job openings, new technologies and new construction methods, construction project bids, APEC information, the latest laws and regulations are posted.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>XML via XSL to HTML, XML</td>
<td>Presentation</td>
<td>Layout of information to end user (user interface) using various platforms</td>
</tr>
<tr>
<td>Servlets and EJBs</td>
<td>Application</td>
<td>Applications and toolsets of business processes, event processes</td>
</tr>
<tr>
<td>EJBs</td>
<td>API</td>
<td>Internal functions/modules to support application development</td>
</tr>
<tr>
<td>Stored procedures</td>
<td>Database</td>
<td>adapters for internal and external databases</td>
</tr>
</tbody>
</table>

*Figure 6. Framework of Internal Architecture (Modified after Dmind (2001)).*

*Figure 7. MVC Architecture (Dmind 2001).*
6.1 Databases

Figure 10 shows the interconnection of databases. Integration of e-Portal and Career Management System allows a more convenient access to both systems, a feature which draws more users. E-Portal must allow users to access various databases to handle their transaction. E-Portal is closely connected with the existing Career Management System in order to support career management services for project owners, contractors and engineers under the supervision of KOCEA. Thus, inconsistency of career records can be avoided.
In order to provide customized information for e-Portal, construction information is classified as shown in Table 3 and organized according to the survey described in Figure 2. The information is broken down into four categories and linked to six modules. KOCEA provides industry information. Corporate information offered by manufacturers is accessible if KOCEA confirms the validity of the given information. Project information is available but limited to public project documents. KOCEA provides on-line training and educational materials based on the professional development requirements.

### Table 3. Contents of Construction Information covered by e-Portal

<table>
<thead>
<tr>
<th>Type of Information</th>
<th>Major Classification Index</th>
<th>Associated Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corporate Information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project Information</td>
<td>e-Projects, e-Engineers</td>
</tr>
<tr>
<td></td>
<td>Individual Information</td>
<td>e-Consultation, e-Engineers, e-Campus</td>
</tr>
</tbody>
</table>

Registering through the e-Portal allows users to have a virtual space at the e-Portal. A user is allowed to create his/her own community and a repository to keep one’s own files and programs. Thus, repository can be opened to the community members. In addition, KOCEA offers professional consultation services through Frequently Asked Questions (FAQ) functions. Qualified professionals from the specialty fields provide on-line answers to the requests from users. KOCEA has also provided electronic training and education materials of over eighty courses to those in need of continuing professional development credits for the renewal of engineering certificates and licenses.

Figure 11 shows transactions between the users and the e-Portal. Verification of the membership and validation of career information are easily completed when the Career Management System (CMS) is linked to the portal. By collecting patterns of information requested, construction
information can be re-organized by the recent preference of users.

The number of visits to the e-Portal is increasing because the portal has been designed according to the suggestions of engineers. Each curve in Figure 12, from top to bottom, represents the numbers of visits to the KOCEA Home, number of IDs issued, Career Management, Open Community, Job Connection, New Construction Project Information, Member’s Community, KOCEA Community, Education and Training, Web Magazine, and Foreigners.

7. CONCLUSIONS AND FUTURE DEVELOPMENTS

A functional framework and a system architecture are identified for a construction e-Portal considering 4-Tier architecture. The architecture is beneficial to enhancing the integrity of the portal due to the variety of information and applications available. In addition, following observations are recommended. Classification of construction information must be defined before the development of e-Portal. This 4-Tier platform is an effective tool in order to allow extension and integration of e-Portal. Using the platform requires less training and education to system operators. To enhance serviceability of e-Portal, its extension is necessary because the changing characteristics of the construction industry. Depending on project delivery methods and contract delivery methods and the definition of contents, additional sub-functions may be necessary.

8. REFERENCES


Construction Sites Communications:  
A Framework for enabling the use of Internet Protocol Telephony in Construction Sites (IPTCS)

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ABSTRACT: Over the past decades, construction firms have been using several off-the-shelf telecommunications services to provide the communication means necessary to their mobile personnel on the jobsite. Despite this the traditional telecommunication systems are nowadays offering a wider range of services to the construction industry, but they are still considered expensive and inflexible. This paper reports on the possibilities of using Internet Protocol (IP) Telephony in the construction industry. The take up of this technology within the industry has not been observed despite the technological advancements in this area. This could be attributed to two main reasons, the slow nature of construction firms to embrace new technologies on the one hand, and the lack of awareness of technologies’ developers and systems integrators to take into consideration the unique nature of construction sites environments needs on the other hand. This issue could possibly be resolved if the two sectors come to understand one another’s requirements. To eliminate the underlying gap between the parties and overcome the implementation barriers of IP Telephony, the authors propose a theoretical framework, referred to in this paper as IPTCS (Internet Protocol Telephony in Construction Sites). It is expected that such a framework will add value to both the services providers and the construction industry supply chain alike.

KEYWORDS: IP Telephony in construction sites; construction sites communications; mobile computing in construction; ICT; VoIP; IPTCS Framework.

1. INTRODUCTION
Overtime, mobile solutions, as part of a larger strategy that includes unified communication and IP telephony, should make communications more efficient and lower costs for telephony use and network traffic (IDC, 2002). On construction sites, workers should be able to benefit from sophisticated communications technologies in order to contribute to the construction performance (Beyh & Kagioglou, 2003). This could be achieved through the integration of Internet Protocol (IP) Telephony into construction sites communications infrastructures. However, the take up of this technology within the industry has not been observed despite the technological advancements in this area, including mobile applications as for example Mobile Voice over IP (Mills-Tettey & Kotz, 2002, Ralph, 2002, Yi-Bing et al., 2001). This could be attributed to two main reasons, the nature of construction firms to slowly embrace new technologies on the one hand, and the lack of awareness of technologies’ developers and systems integrators to take into consideration the unique nature of construction sites environments needs on the other hand. This issue could possibly be resolved if the two sectors come to understand one another’s requirements. To narrow the wide gap between the parties and overcome the implementation barriers of IP Telephony, the authors propose a theoretical integrated framework. It is expected that such a framework will add value to both the services providers and the construction industry supply chain alike.

This paper is organised as follow: Sections one and four provide introduction and conclusion respectively. Section 2 briefly describes the Internet Protocol paradigm and section three presents the IPTCS Framework (Internet Protocol Telephony in Construction Sites) developed by the authors at the Salford Centre for Research & Innovation within the School of Construction & Property Management at the University of Salford.
2. INTERNET TELEPHONY

Internet Protocol (IP) Telephony has first emerged from a combination of three core technological components including 1) the Internet, 2) Computer technology and 3) Telephony. The earliest history of IP Telephony was plagued with poor voice quality and substantial delays (Beyh & Kagioglou, 2003) and its use was restricted almost to computer hobbyist (Dettmer, 2002). IP Telephony uses data packets to transmit voice, video and other services over the Internet instead of the transport over the Public Switched Telecommunications Network (PSTN). This mechanism significantly decreases call charges (Das, 2000) and allow convergence between different telecommunications services over a single data network. The technology is now reaching a high level of advancements and describes a total end-to-end solution from a user’s perspective that gives the opportunity for advanced applications potentially yielding real business benefits (Catchpole et al., 2001).

However, despite its continuing improvements, IP Telephony still is at its very early stage of diffusion within the business environment and its slow uptake is likely to continue for many years ahead.

3. FRAMEWORK FOR ENABLING IP TELEPHONY IN CONSTRUCTION SITES

Constructions sites generally lack effective and adequate communication means where the entire supply chain along with the work forces are constantly put in a continuing collaboration process. One of the key success factors identified by Kennedy & Sidwell (2001) as prerequisite in implementing re-engineering in a construction industry context is an effective communication cycle between major project participants which is found to help avoiding rework and reduce time. Moreover, in many cases, the participants are geographically distributed, making the need for effective communication technologies acute (Anumba et al., 2001). Furthermore, introducing Internet Telephony to the construction industry as an adequate communication means that is able to succeed where the traditional telecommunications systems have failed is believed to be a very challenging path and it may not be easy to cross over without a clear understanding of the different issues and steps involved in the integration process. Based on this philosophy, the authors believe that there is a justified need for a common framework that will help ITSPs, Construction Firms and Equipment Vendors alike to come together in order to accelerate the integration of IP Telephony in construction sites environments.

The IPTCS Framework is based on four main inter-related variables identified as important to the implementation problem as shown in Fig. 1.

3.1. Environmental Barriers

Sekaran (2000) indicates that an independent variable is a variable that influences the dependent variable in a negative or positive way. It is assumed that the slow uptake of IP Telephony within the construction industry is proportionally related to several environmental barriers such as technical, financial, cultural and organisational affecting its adoption by construction firms (Fig. 2).
Technical Barriers:
Wireless Voice and Data over Internet Protocol solutions will undoubtedly fill an important role in the evolution of enterprise communications. The impact of successful, widespread adoption of advanced ICTs in the construction industry could be very significant as stated by Bower et al. (2001) who further indicate that “with the increasing accessibility and affordability of communication technologies could come the emergence of globally-based virtual organisations operating in knowledge-driven markets from geographically remote locations”. However, there are numerous reasons why these solutions have not yet reached their full potential in the construction sector as for example, one impediment for many people and firms is simply “the fear of technology” as 10-15 % of the population will retire out of the industry before they ever embrace technology according to Stark (2003). Yet, in order to drive construction firms to look closely at such a technology, IP Telephony and wireless technologies system developers and equipment vendors must meet several concurrent goals to overcome the technical barriers preventing its integration in today’s demanding construction sites environment and similar terrain topologies. Therefore, they must address the various needs of the construction industry. Moreover, considerable technical improvements are constantly being observed and recently an exciting opportunity for Voice over Internet Protocol has emerged using a Personal Digital Assistant (PDA) empowered by a Wi-Fi (Wireless-Fidelity) VoIP system developed by Pocket Presence (Linden & Blom, 2002). But the delivery of wireless XoIP (Voice, Video and Data over Internet Protocol) services on portable handheld and computing devices to construction sites should be taking into consideration several important factors that must entirely comply with such environment. These technical barriers include but are not limited to the following issues:

- XoIP wireless devices must be robust, water proof, resistant to dust and shock and equipped with adequate and self sufficient power supply similar to the traditional systems conditions as identified by Bowden (2002)
- XoIP features and services must exceed the capabilities of traditional and conventional phone systems
- Sound and video transmission quality must meet an appropriate level required by the information need under consideration in construction sites.

- Mobile and wireless devices must be interoperable and “plug-and-play” enabled in order to be seamlessly deployable
- Internet bandwidth must be prepared to meet IP Telephony requirements

Furthermore, major technical barriers of IP Telephony deployment are such created by wireless LAN connectivity. In such a networking environment, client devices handle the call set-up and other management issues which are usually controlled by a cell phone service provider infrastructure in the traditional systems. This issue will consequently increase the challenges that may be encountered while deploying an acceptable and effective wireless XoIP network. Moreover, it is well known that transmission of communications over IP network is synonymous to packet loss, delay and jitter issues. These are even higher in a wireless network especially when client devices are roaming between hot spots, unlike circuit-switched communications where voice quality is consistent throughout a call, the quality of a VoIP call can vary on almost a packet-by-packet basis (XACCT, 2001). Also, the fact that several standards exist creates interoperability problems causing communications difficulties between Gateways from different vendors because, many vendors have proprietary solutions, and even Gateways supporting H.323 standard may not work with each others (Nguyen et al., 2001).

Another issue challenging the IP Telephony deployment is related to the Quality of Service (QoS) performances of wireless voice over IP networks. QoS is in fact a critical issue to be resolved for achieving the migration from circuit-switched to packet-switched telephony networking (Mishra & Saran, 2000). The public switched telephone network (PSTN) defines quality of service as a particular level of service, for example “toll-like” service. However, quality of service for voice or other media over the Internet Protocol is defined as a continuum of levels, which are affected by packet delay or loss, line congestion, and hardware quality (Intel, 2002).

Noteworthy that IP Telephony emergency services such as Enhanced 911 or E911 calling standards are still in the early stages of being defined (Avaya, 2002), such services provides crucial information for the different emergency departments in order to provide the most accurate and timely response.

Financial Barriers:
Investing in new communications technologies and systems should have the potential to allowing an adequate and rapid “Return on Investment (ROI), construction firms may not be willing to undertake any new investment of the kind before taking full advantage of their existing systems in which they may have already heavily invested unless there is an immediate need for it. The cost of technology is believed to be an important barrier to adoption that a number of companies point to when explaining their reluctance to implement wireless solutions, even though they recognise the value of the devices and applications (Stark, 2003). These barriers within the construction industry were also identified by Love et al. (2001) who state that this business like others relies on cashflow availability and thus, firms could not invest in technologies that would not bring about immediate benefits. The financial barriers they are referring to include:

- The cost of system requirements and maintenance;
- Investment risk;
- Amount of available credit;
- Cost of training and education;
- Losses in productivity; and
- Market uncertainty.

Cultural Barriers:
“Companies that want to survive the increasingly sophisticated and competitive global marketplace will be required more and more to follow technical developments worldwide” as stated by Ashton et al. (1991), this is however a serious issue for the construction industry to follow such technological advancements at an early stage of developments and even after maturity because it is well known that in general, people in construction are in their nature, reluctant to change. According to Love et al. (2001) it would appear that contractors have ignored emerging technologies that have the ability to provide significant performance improvements. This fact is mainly due to the difficult environment and working conditions that usually physically and mentally affect workers at the jobsite or in the office. The fact that new technologies are continually emerging, they often require significant efforts for training, test, and experimentation. DIST (1998) emphasises the difficulties in the construction industry of adopting new Information and Communication Technologies by a resistance from the management to change and a belief that the industry is doing well without it. Moreover, training any personnel on new technologies take

... time and considerable efforts for a construction firm to achieve and therefore, adopting new technologies or accepting to experimenting them is often related to what has been learnt previously from past experiences. Therefore, in order to be successful, a migration to, and adoption of new technologies must strongly consider looking at consequences where an attempt to change the users’ culture is likely to take place; in fact, change is a complex psychological event as stressed by Andersen (1992) who believes that “Just the thought of changing the fundamental culture or strategy of an organisation can send shock waves throughout the organisation, causing emotional and psychological stress to the individuals”, because change is often asking people to do something different, adopt a different belief or attitude, therefore, prior to initiating any change it is necessary to analyse the organisation, the employees and their readiness for change.

It may be therefore debated that people’s culture in the construction sector may strongly, negatively or positively affect the decision to integrating new technologies such as IP Telephony communications, this includes the issues arising from the preparation of the migration phase from traditional systems to IP Telephony one. The implementation of internal informational plans, network assessments and upgrade, purchase of new equipments and devices, and personnel training could seriously affect the decision to undertake this move; it is therefore believed that strategies where technological threats and opportunities are well understood should strongly contribute to the acceleration of adoption or in the contrary, the clear denial of such an eventual migration.

Organisational Barriers:
Andersen (1992) stresses that “the construction industry and its employees are being impacted by technology. The industry is affected by the use of computers; fax machines, telecommunications, new products, equipment, and robotics. Demographics clearly indicate the lack of technological skills in the upcoming work force. The educational level of employees will need to be increased to meet these challenges. Current employees will need training, retraining, and cross training to keep abreast of new technology”. Bennett and Durkin (2000) indicate that organisational change significantly influences employee commitment to the organisation especially when the perceived values of the organisation have changed. Moreover, various
situations or events occurring within organisations are shown to influence commitment levels among employees. One particular situation that has received a fair amount of attention is when an employee’s work environment undergoes significant changes (Meyer & Allen, 1997).

3.2. Moderating variable
Internet Telephony Service Providers (ITSPs) and Equipment Vendors (EVs) are assumed to have a strong contingent effect on the relationship between the environmental barriers and the implementation of IP Telephony in construction sites. They are selected as moderating variable to discover whether they modify the relationship of the independent variable to an observed phenomenon (Burns Robert, 2000). This phenomenon is represented in this given situation by the implementation of IP Telephony in Construction Sites. Moreover, ITSPs and EVs are expected to play a strategic role vis-à-vis construction firms in order to encourage the migration from traditional telecommunication systems to IP Telephony ones. Although, IP Telephony may not be for everyone, particularly organisations that have basic phone systems and need only a phone to dial out and receive calls (Chan, 2003), ITSPs and EVs could demonstrate a real interest to construction firms in terms of building open solutions that fit with their working environments. Furthermore, most organisations have made significant investments in their existing voice, video, and data networks which they naturally need to protect, therefore, a low-risk migration path is required from the old world to the new world as stressed by Cisco (2002), the role of ITSPs and EVs in this given situation is to develop solutions that facilitate the deployment of/or transition to IP Telephony networking in mobile and difficult environments. Such transition should be transparent to users and there must be a strategic alignment between what does already exist and what would come as a replacement to it, equipment, handsets, dialling plans and services including voice messaging, call restrictions, call transfer, multiparty conferencing, etc. need to be similar or even easier to use than in the traditional systems.

3.3. Intervening Variable
An intervening variable is a variable that helps to conceptualise and explain the influence or effects of the independent variable on the dependent one (Burns Robert, 2000, Sekaran, 2000). This is defined as a set of an established Enabling Process that surfaces between the barriers and the implementation of IP telephony at the jobsite (see fig. 3).

![Figure 3: The Enabling Process of IP Telephony in Construction](image)

In an age where technology itself is becoming an increasingly important component of the ability of companies to compete and even survive, the capacity to identify emerging technologies and manage them are vitally important issues (du Preez & Pistorius, 2002). Moreover, most changes (social, economical, environmental, etc) are directly caused by and/or related to the development, perception and use of technology as indicated by Drejer (2002) who further stresses that “Key traits of the technologically related changes are that they tend to transgress physical, organisational as well as disciplinary boundaries. Fig. 3 represents the main steps involved in the process that is believed to enabling IP Telephony communications within the construction industry. A collaborative working body including ITSPs, Equipment Vendors and end users from the construction industry sector is to be structured; such collaborative work must look at the following process:

**Users Involvement & Education:**
The involvement of the end users in the conceptualisation of the communication network that is intended to be integrated to/or replacing their existing systems could naturally narrow the adoption gaps and would further contribute to a rapid implementation within the firm. Stitz of McAnninch Corp. as indicated by Stark (2003) has involved his field personnel in decision along the way for the adoption of a new wireless technology, because they are, after all, going to be the primary users of these tools saying:

“I think the biggest reason (adoption) is working so well is
because I involved them from the start. I asked them what information they would like to see and how they would like to see it, and they actually helped me design the specs for the software. They were involved from step one, so I think that helped a lot”.

Moreover, involving the employees in the conceptualisation process should contribute to the following benefits:

- Developing a clear and shared understanding of what is meant by migrating to IP Telephony communications
- Facilitating the involvement of the employees at all levels and stages of the development and implementation phases
- Developing strategies, set targets and participating in network evaluation measures.

Therefore, the involvement of people within the firm should be a systematic approach to maintaining a successful migration to such new technologies in terms of integration, implementation, evaluation and network sustainability.

_Firm’s Existing Communications Means Assessment:_

This audit exercise will permit the identification of eventual gaps and issues in the firm’s IT networks. It will also contribute to defining a clear vision of what is expected from an IT system. A business vision is vital for a good strategy formulation, because it functions as a co-ordinating directive framework (Klouwenberg et al., 1995). A thorough audit should therefore help the construction firms to raise several questions such as:

- Are our existing telecommunications systems adequately supporting our major construction sites communications needs?
- Do these systems satisfy our construction teams’ mobility?
- Are they available to the entire construction team members?
- Do these systems permit adequate communications with the supply chain?
- Could an IP Telephony solution improve our global communications mechanism?
- Can new services be created and offered to all members?
- Can we reduce our global communications cost?
- Can IP Telephony improve our communications with our clients and contribute to gaining new markets?

_IP Telephony Assessment:_

The assessment of IP Telephony systems and the identification of its benefits, advantages and drawbacks should be naturally benchmarked with the firm’s existing legacy systems. Despite the rapid growth of the technological developments and advancements in IP Telephony, there is still much more concern with interoperability between equipments and services from different vendors than with the quality of service itself. Therefore, it must be a systematic approach to assess and compare the equipment, software, solutions and services with regards to several criteria such as:

- Interoperability
- Scalability
- Services availability
- Support and maintenance
- Training and knowledge transfer, and
- Cost

As it is the case in the traditional telecommunications systems, services providers are concerned with interconnection between their different networks at a national and international scale; there is also a deep concern with compatibility between equipments from different vendors, this is again true in IT and IP Telephony situation. In the traditional telecommunications world “if a subscriber to a certain mobile communications carrier cannot make a call to a subscriber of another carrier, people lose an incentive to purchase cellular telephones, or try to subscribe to a carrier that boasts dominant number of subscribers” (Watanabe et al., 2003), therefore compatibility will add value to the network providers and equipment vendors as much as to the end users and customers alike and this criteria should also be considered in IP Telephony communications world.

_Technological Alternatives:_

It is assumed that in most construction projects, the communications infrastructures are absent at the jobsite under consideration. The preparation of an adequate telecommunication network could be seen as an independent project itself leading to frustration, budget and resources involvement and a lot of time anticipation. An alternative to such undesirable but necessary work is that a movable and ready to operate IP Telephony communication unit could be designed to respond to such construction situations. A single Internet over
Satellite (IoS) connection point to the central unit could provide a vital communication link between the movable IP telephony unit on site and the entire supply chain. Such a unit could contain basic or a complete range of IP and legacy communications equipment and users’ terminals according to the projects and personnel needs. Knowing that IP Telephony equipments, terminals and solutions are rapidly becoming cheaper comparing to the legacy telecommunications solutions, construction firms would therefore be able to acquire these units more easily.

3.4. Dependent Variable
IP Telephony Implementation in Construction Sites is assumed to be dependable on the relationships and processes set between the other entire ranges of variables (Burns Robert, 2000, Keppel, 1973, Sekaran, 2000). This dependency however, should be further discussed after obtaining the finding results of the ongoing field investigations undertaken by the authors.

4. CONCLUSIONS
This paper has discussed the integration of IP Telephony into construction sites and presented the possible benefits that could be obtained to improve the communications exchange between the project teams while reducing the overall communication costs. A theoretical framework to achieve such integration has been conceptualized. The main steps involved in this framework are explained. However, the authors believe that by identifying the barriers that are actually preventing the adoption of IP Telephony technology by construction firms, the latter along with ITSPs & equipment vendors, will be better positioned to overcome the most encountered challenges in the future and thus, the adoption process could be diffused in construction sites’ environment more rapidly.

5. REFERENCES
Cisco (2002). The strategic and financial justification for IP communications

IDC (2002). Improving worker productivity and revenue generation with unified communication, Improving worker productivity and revenue generation with unified communication, Report#: IDC# 24983.


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ABSTRACT: This paper presents the design of an XML-based document flow management system, called X-DFM (XML-based Document Flow Management), for increasing efficiency in processing documents in construction projects. X-DFM provides four services via Web Services: the document flow services, content management services, authorization services, and message services. The document flow services are designed based on the wfXML standard and with the consideration of flow processing security. The content management services support not only management of an XML document as a whole but also the contents in the document. The authorization services provide authorization controls of user accounts and system functions. The message services support message passing among users and between X-DFM components.

KEYWORDS: document flow management, content management, system integration, Web services, XML.

1. INTRODUCTION

Construction projects usually require sharing and processing of large amount of documents, such as reports, drawings, contracts, standards, and so on, among a number of participating parties. Furthermore, document processing flows in the lifecycle of a construction project, spanning across planning, design, construction, operation, and maintenance phases, can be quite complicated and usually involve many people of various roles in the project. Traditional paper-based document processing that relies heavily on manpower is not efficient enough to meet the need of modern construction projects that are often large and complex. In addition, the participants are often located at different places but may want to get access to the construction information or even perform document processing at their convenient time.

With rapid advancement of computer technologies in recent years, many software systems have been developed to facilitate electronic document processing for construction management. Several of them also take advantage of WWW (World Wide Web) technologies to provide Web interfaces for easy access from anywhere at anytime. However, the introduction of these advanced document-processing systems into a construction project often involves integration of the new systems with the already existing legacy systems. From the user’s point of view, all application systems involved in a project should ideally be integrated to act like a single system with uniform user interfaces, unified user account management, and integrated data management. But, from the system integration engineer’s point of view, achieving this requires many difficult system integration tasks that usually involve good understanding of the underlying data structures of the legacy systems.

Because most of the legacy systems do not provide APIs (Application Programming Interfaces), one common approach to integrate with a legacy system is through direct access to its database. Although this approach may solve the integration problem at the moment, it often makes the maintenance of the integrated system difficult and causes greater complication and difficulties for future system integration tasks.

Recently, an emerging technology, called Web services [Newcomer] [Deitel], has been evolving rapidly on the World Wide Web as the need for interoperable system-to-system communication grows. Web Services technology provides a standard means of communication among different software applications and, therefore, has the potential to provide a better solution for system integration. It employs XML (eXtensible
Markup Language) [Deitel], an open standard for data exchange, to define messages for communication and how the messages are processed via common Internet protocols (e.g., HTTP). A standard reference architecture for Web services has also been proposed by the Web Services Architecture Working Group at the World Wide Web Consortium (W3C) to promote interoperability and extensibility among software applications, as well as to allow them to be integrated for more complex operations [Harold].

In this paper, the design of an XML-based document flow management system, called X-DFM, is presented. The focus of the design is on how to integrate both legacy systems and new systems within X-DFM using Web services technology so that the reusability, extensibility, and maintainability of X-DFM can be maximized. In addition, discussions are given on the design of the four services supported by X-DFM to facilitate efficient document processing in construction projects.

2. DOCUMENT FLOW MANAGEMENT

The document flow management for this work consists of two major parts. The first one is the control of the processing sequence of the document. Usually, a workflow engine is applied to achieve the management and automation of the document flow. In this research, we follow the WfMC (Workflow Management Coalition) standard to design our flow management system. The second part concerns with the review and editing of the document itself. The document may be processed and managed as a single entity or the contents of the document may need to be processed and managed as separated entities. We refer the former as document management while the later as content management. The X-DFM system designed in this work provides not only document management, but also content management.

Management System is defined by WfMC as “a system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke the use of IT tools and applications [W3C].” Figure 1 shows the workflow reference model proposed by WfMC, which identifies components and interfaces needed in a workflow management system. The workflow enactment service consists of one or more workflow engines to create, manage, and execute workflow instance. The interfaces around the workflow enactment service are called WAPI, which is a set of functions to access and regulate the enactment service. Process definition tools are used to define workflow processes, including the activities’ relationship, participants, criteria to start or to terminate the process, associated documents, etc. [WfMC 1999a]. Both interface 2 and interface 3 are defined for the enactment service to invoke and control other applications [WfMC 1999b]. Interface 4 is used to connect other workflow enactment services. Interface 5 is used to connect the administration and monitoring application [WfMC 1998]. The design of the workflow management services in X-DFM follows the workflow reference model shown in figure 1.

Figure 1. Workflow reference model [W3C].

The term “content management system,” as opposed to document management system, reflects the fact that such systems generally allow for breaking a document into discrete content fragments, rather than having to manage each document as a whole. Not only does this simplify such things as how to coordinate the work of multiple writers working on the same document, but also it allows users to assemble entirely new documents from existing document components. [Liu]

Generally speaking, content management systems usually provide the following capabilities: [Chen] [Freter]

- Version control: see how a document evolves over time.
- Content sharing: see in what business processes the document content is used and re-used.
- Electronic authoring: enable users to edit and revise the contents of electronic documents.
- Electronic review: enable users to add their comments to the contents of a document without actually changing the document itself.
- Access control: define the different types of access privileges to the document contents for different types of users.
- Publishing management: control the delivery of documents to different publishing process queues.
- Workflow integration: associate the different stages of a document's life-cycle with people and projects with schedules.

The design of the content management services in X-DFM focuses on the version control, content sharing, electronic authoring, and electronic review. The authorization services and workflow management services are designed in collaboration with the content management services in X-DFM to support the services related to access control and workflow integration, respectively.

3. SYSTEM ARCHITECTURE DESIGN OF X-DFM

The architecture of the X-DFM system can be divided into three tiers as shown in figure 2: user interface, business objects, and Web Services enabled (WS-enabled) application servers, which consist of both newly-developed systems and legacy systems with Web services adapter. Four services are provided by X-DFM through WS-enabled application servers: the document flow services, content management services, authorization services, and message services. A brief description on the major components in the architecture shown in figure 2 is given as follows:

- X-DFM user interface: It is designed to provide personalized web-based GUI (Graphic User Interface) for easy access and ease-of-use. With an appropriate account, the user can login X-DFM through Internet or Intranet from any places and at any time using a common web browser, e.g., Internet Explorer. Upon login, the user will see a list of messages containing notification and instructions of all document-processing jobs he or she is expected to perform at the moment. Figure 3 shows the document-processing flow for a user. The user first retrieves one of the messages in the list from the message services. Based on the instruction in the message, the user then tries to check out the documents needed for performing the job from the content management services. After checking the user’s authorization privilege by authorization services, X-DFM returns to the user only the contents in the documents he or she is asked and allowed to review and/or modified. When the user completes the document-processing job and checks in the documents, he or she then notifies the document flow services that will then follow the pre-defined flow for next-stage document-processing.

- X-DFM business objects: X-DFM business objects are classified into two types of components: interface components and business components. The interface components are designed to support the implementation of the X-DFM GUI, while the business components provide internal business transaction results and information integration from different WS-enabled application servers.

- WS-enabled application servers: all of the services provided by X-DFM are through a set
of WS-enabled application servers that are integrated by the X-DFM business objects. The WS-enabled application servers can be newly developed systems that support Web services or legacy systems with Web services adapter. Because Web services technology is employed to support loosely coupled integration between the business objects and the WS-enabled application servers, adding new services in X-DFM can be done easily by adding the corresponding new WS-enabled application server and business objects without the need of modifying existing WS-enabled application servers. Design of WS-enabled application servers for X-DFM will be discussed further in Section 4.

Web services technology is employed in the architecture design of X-DFM (see figure 2) to achieve flexibility in system development, to ease the system integration task, and to increase system extensibility, maintainability, and reusability. Services in X-DFM can be developed independently in the form of WS-enabled application servers that may run on machines with different operating systems and distributed at different locations. In addition to the newly developed WS-enabled application servers, legacy systems can be made WS-enabled through the design of Web services adapters and integrated into X-DFM. With standard communication protocols established between X-DFM business objects and WS-enabled application servers using Web services, the addition of new application servers and replacement of old application servers by other equivalent application servers in X-DFM can be done easily with minimized system modification. Furthermore, because the WS-enabled application servers are independent servers, they provide services to not only X-DFM but also other systems through Web services.

4. DESIGN OF WS-ENABLED APPLICATION SERVERS

X-DFM provides four major services to help engineers in concurrent document processing: authorization services, the document flow services, content management services, and message services. There are four major corresponding subsystems in X-DFM to support the four services: user management system, flow management system, content management system, and message center (see figure 4):

- User management system: It allows the administrator to manage user accounts, organize user groups, and perform authorization tasks.
- Flow management system: Its design follows the WfMC standard and the Wf-XML specification. It allows users to pre-define commonly used process flows and save them as templates. The user can then use the pre-defined process flow from templates or create a new process flow for the task at hand.
- Content management system: It provides services for version control, content sharing, electronic authoring, and electronic review of the document contents.
- Message center: Two types of messages are handled by the message center. One type is a notice from the flow management system to remind the users about their document-processing tasks. Another type is a correspondence between the users. If one leaves a message to another in the message center. The message is then delivered thru the e-mail system or posted on the recipient’s X-DFM working webpage.

Every subsystem in X-DFM is designed as an independent WS-enabled application server. It usually has its own user interface and provides services to X-DFM or other clients via Web services. For a newly developed WS-enabled application server, a 4-tiers architecture framework is proposed (see figure 2). Different from the common 3-tiers architecture, consisting of presentation tier, business logic tier, and data
tier, a Web service tier is added between the presentation tier and the business logic tier in this 4-tiers architecture. The Web service tier is designed to enable Web services on all business functions of the system. It also provides a layer of encapsulation for all business objects in the business logic tier. The graphical user interfaces in the presentation tier are implemented using the business functions (in the form of Web services) provided by the Web service tier. The clients can obtain services from the system through either user interfaces provided in the presentation tier or direct interactions with the services in the Web service tier.

For taking advantage of legacy systems in this framework, a Web services adapter is needed to turn a legacy system into a WS-enabled application server. The implementation of the Web service adapter may involve interactions with the business tier and the data tier of the legacy system. If the legacy system supports an API (Application Programming Interface) or allows direct access to the business objects in the business tier, the Web service adapter can be implemented using the API and/or the business objects. Otherwise, the Web service adapter is implemented through direct interactions with the database in the data tier of the legacy system.

5. COMPONENTS DESIGN IN X-DFM

In this section, the authorization service component is used as an example to discuss the design of components in X-DFM.

Figure 5 shows the design of the authorization service component in X-DFM. The ACL (Authorization Control List) class between the CIdentity and CAnyObject classes is designed to establish authorization relationships between the system objects that need access control (e.g., files, documents, and operations) and the users. Users may have various authorization privileges on system objects at the same time depending on their job functions and the roles they play in a project. Both the CIdentity and CAnyObject classes are abstract supper classes and have no instances. All objects of the derived classes of the CAnyObject class have their access controls managed by a set of ACL objects.

From the point of view of authorization, the ACL component is in the Web service tier, while the rest of the components is in the business tier of the WS-enabled authorization service application server (see figure 5). In X-DFM, to set up the access privilege of a system object for a user, the authorization object in the business tier of X-DFM sends a request to the ACL’s Web service with a simple XML message like this:

```xml
<AUTHORIZATION system="X-DFM" method="set">
  <IDENTITY>boyce</IDENTITY>
  <OBJECT>000001</OBJECT>
  <PERMISSION>GRANTED</PERMISSION>
</AUTHORIZATION>
```

In the message, the IDENTITY value can be the value of lSID of the CUser class or the CRole class, both inheriting from the CIdentity class. The OBJECT value can be the value of OID of the classes inheriting from the CAnyObject class. The PERMISSION value can be set GRANTED or DENIED. If it is not set, the default value is NODATA.

For checking the access privilege of a system object for a user, a simple request message in XML sent to the ACL’s Web service is like this:

```xml
<AUTHORIZATION system="X-DFM" method="request">
  <IDENTITY>boyce</IDENTITY>
  <OBJECT>000001</OBJECT>
</AUTHORIZATION>
```

The XML message responded from the ACL service is then like this:
<AUTHORIZATION system="X-DFM" method="respond">
  <IDENTITY >boyce</IDENTITY>
  <OBJECT>000001</OBJECT>
  <PERMISSION>GRANTED</PERMISSION>
</AUTHORIZATION>

6. CONCLUSIONS

In this paper, the design of an XML-based document flow management system, called X-DFM (XML-based Document Flow Management), has been presented for facilitating document-processing tasks in a construction project. The design takes advantage of the evolving Web services technologies to achieve flexibility in system development, to ease the system integration task, and to increase system extensibility, maintainability, and reusability. The difficult issue on integration of new application systems and legacy systems has been addressed in the design of X-DFM. In addition, four essential services have been proposed and designed in X-DFM to support document flow management services: the document flow services, content management services, authorization services, and message services. It is hoped that the design ideas presented in this paper can shed some light on designing construction management systems with great flexibility, extensibility, maintainability, and reusability.

REFERENCES

[Newcomer] Newcomer, E. 2002, Understanding Web Services, Addison-Wesley, Boston, USA.


Analysis of the most commonly used platforms for the management of construction projects in Spain

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ABSTRACT: The 1990s have seen a technological shift in the construction sector from IT driven solutions to IT enabling ones. Not only IT companies but also construction companies are continually investing, evaluating and focusing on new technologies to create collaborative spaces among different participants geographically dispersed and to share information among partners in the design phase, in the supply chain, in the construction process, etc. Many different services are there in Internet for the construction sector that fall into four categories: One of the services are electronic brochures that are portals based around manufactured product and tend to duplicate paper-based catalogues. There are also on-line portals, which enable e-commerce and have links to Standards, industry news, databases of selected professionals in the industry, etc. For the management of construction projects we can find project collaboration services or extranets that are focused on tools and services that make it easier to manage the AEC projects. Common services include backing up files, keeping a document revision history, tracking who accesses what files. Finally, there are full service portals. In addition to project management tools, full-service portals provide services such as community forums where you can chat with other project managers and share knowledge resources. Other services may include online catalogs for finding materials and subcontractors.

In this Paper we will expose the different kind of IT services that are available for the construction sector in Spain and some examples of how various companies have taken advantage of this new methodologies

KEYWORDS: Construction Project Management, Platforms, Web services.

1. INTRODUCCIÓN

Project management and projects are not new concepts but projects today are far more complicated than ever before. They involve larger capital investments, embraces several disciplines, widely dispersed project participants, tighter schedules, stringent quality standards, etc. These factors coupled with high-speed developments in Information and Communication Technology (ICT) have influenced project management practices to take a new turn taking advantage of newly developed management tools and the latest technology (Alshawi, 2001).

Nowadays, the handling of information and its access has been converted into essential factors for the economical development and business success. In the last years, Information Society and basically Internet, has become the main information transmission and communication media among companies.

In Spain, the construction sector holds more than the 7% of the GNP (Gross National Product) and more than 270.000 business. Moreover, the giants of the sector (less than about ten companies) share out around the 10% of the invoicing while the 90% are hold by an enormous quantity of SMES (Small and Medium Enterprises) and autonomous. Probably, the construction industry is the geographically most dispersed and involves a big quantity of small and medium enterprises. The variety of professionals in a project can easily cover dozens of disciplines from architecture, engineering to installations and demolition, all with very different information requisites. Both, the improvement of IT and the characteristics of the construction sector have lead to the creation of many different web services focused on the construction sector.
2. BACKGROUND

As there are many services offered not only for the management of construction projects but also for information, marketing, ordering, etc. We will start defining some terms so as to clarify the following information.

Electronic business
Includes
• electronic trading of physical goods and intangibles such as information,
• all trading steps such as online marketing, ordering, payment, and support for delivery
• electronic provision of services, such as after-sales support or online legal advice
• electronic support for collaboration between companies, such as collaborative design

Electronic commerce
Is considered as the subpart of e-business that is focused on e-procurement, e-buying, e-payment, etc, representing ‘punctual’ operations of short duration.

Portal
Web sites targeted at specific audiences and communities, providing content aggregation, relevant information, collaboration services and application access. A portal should provide:
• Connection to the resources of the Internet through search engines, shopping engines and other utilities
• Content like appropriate news, legislation, etc.
• Commerce involving access to electronic shopping and other commercial activities
• Community of interests that are basically tools to enable participants to interact.

Electronic marketplaces
A web site that offers transaction functionality between two or more companies. Usually, it offers additional functionalities like product catalogue management, biddings, etc.
Electronic marketplaces are one of the most significant developments of the Internet age to date.

Application Services Providers (ASP)
These services are third-party entities that manage and distribute software-based services and solutions to customers across a wide area network from a central data center. In essence, ASPs are a way for companies to outsource some or almost all aspects of their information technology (Martinez, 2002).

3. THE BEGINNING OF INTERNET IN CONSTRUCTION

The main reason why the construction sector has entered in Internet is the own potential of this market. In fact, the proportion of GNP the Spanish construction market is one of the biggest. Moreover, the fragmentation of this sector let everybody imagine an Internet portal capable of grouping together all SMEs (Salvatierra, B, 2002).
In Europe, the construction sector presents a great fragmentation due to, partially, the absence of normalization. Internet is a global environment and requires a unified working process.
In Spain the creation of specialized portals in the construction sector has a considerable delay in relation to other countries.
Recently, the development of portals for AEC and the infrastructure to support them has increased a lot both at commercial and research level.
Many construction portals have been launched in Spain over the last two years, in line with similar trends across all industries. Several of these portals failed within a short period of time indicating the tight marketplace within which they are competing, and the lack of known business models for successful systems.

4. INTERNET AND PROJECT MANAGEMENT

The advent of various new technologies, with the potential to address some of the limitations facing current project management practices has created a major impact on many organizations. Foremost of the new technologies is the Internet, which offers the platform for more effective communication. Many businesses throughout the world use this technology as a channel to communicate or to exchange information. The Internet has also embraced the construction industry, that it could be used as an efficient tool for communication to bring together the widely dispersed project participants and multinational project teams. On the other hand, a few are under the impression that the Internet provides an automatic solution to the fractured communication system in construction.
5. INTERNET AND COMUNICATION

Communication is a broad term. We can distinguish between: information access and interactive communication.

Some of the internet services for the construction sector are based on ‘Information Access’, there are portals where groups of interested people can visualize information of an specific topic like legislation, databases, advertising, events, etc. **Information Portals** are those portals for more general use, offering information as main resource, with classified links to other sites, without transaction functionality among companies.

Other Internet services are based on interactive communication and basically on data management so as to carry out the management of the constructive project. **Enterprise Portals** are those portals centered on the operations of an enterprise offering information and transaction functionality for stakeholders of a since company. Project management features can be also available. This kind of site can be based on Internet, Intranet or Extranet or in a combination of these ones. Data exchange can be generically defined as the process of transferring relevant information between different construction parties with the aim of minimizing data re-entry and duplication. Data exchange can take place across several organizations, construction applications, professionals, etc. Such an exchange involves different types and amounts of information depending on the nature of the organization, experience, project, etc.

6. THE EVOLUTION

It’s nearly 10 years from the beginning of the mass commercialization of Internet, the media that has progressed in an exponential way. Firstly, in its origins, the use of Internet was basically to show information, a place where users and companies could place their personal web pages free. The main objective was to disseminate the image and characteristics of their company. The evolution tended to join communities of users, professionals, etc. in different spaces, which was called Virtual Communities and Portals. A portal is ‘The web page where to aggregate contents and functionalities, organized in a way that facilitates the navigation and gives the users an entrance to the Net with a huge range of options’. Therefore, users have the services and products of an area of knowledge that might need all together.

Later, companies felt the necessity to offer services (included sells trough Internet, called e-commerce) and improve their contents. Now, the strategy of Internet is not only to ‘be’ there but also to ‘do’.

Not only after some years of the beginning of the first portals, the construction sector entered in Internet. At the beginning of the year 2000 the first specialized portals in the area of construction in Spain shown up. When the first five or six construction portals b2b began to run, the big Spanish construction companies created their portals b2b. Their objective was to create platforms for the electronic commerce centered basically in construction materials.

In 2001 a dozen of portals appeared in the construction sector, like Uralita, E-difica, Build2Build, BuildCom, Urbaniza or Bricsnet. The question is ‘Is there enough market for too many specialized portals?’ If the users have too many similar webs with the same services and very little difference between them, it generates confusion and dispersion. Due to, in less than a year, a great quantity has disappeared and the others have fused.

For Vicente Martinez, general director of Germinus, the success of the specialized portals depends on the inverted money, as well as high level of professional contents of information. Portals must have a potent technologic partner in Internet, a consultant that knows the net and business models in Internet and on top of all; it must count with the support of a sectorial leader (Gilarranz L, 2002).

The fact that the market tends to a globalization is that in March 2002 the big portals of the Spanish construction fused in a new company called Obralia. Small and medium enterprises are those who will benefit from those portals to be able to have access to a big market and use the same technology as the big ones. The main objective of this new stage is to offer not only the transactional tool best adapted to a sector in which constructors and suppliers could buy and sell materials through Internet with all its advantages but also web project management services.

What about the future? Is it possible in a near future to make all the professionals involved in all the stages of the construction process walk close to their computer connected to Internet? This is the direction that construction must follow. It should tend to a renovation and a training of all the participants of the construction process.
### 7. DESCRIPTION OF THE MOST COMMONLY USED WEB SERVICES

**Table 5. Summary of the main construction portals and their services**

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In this table the main construction portals and their services are summarised.

Construplaza provides general information about the sector, events, and legislation. As e-marketplace, the site offers services of e-catalogues and b2b transactions. Obralia offers ASP services to sell and buy products, management of offers and demands and e-cataloguing system. Construnario is an Internet portal with a construction-oriented dictionary and...
searcher; Structuralia is also an Internet portal with general information (events, publications, software, job opportunities, etc). The site offers e-work services to support outsourcing and workflow as well as e-learning services. Afterwards, we classify these services into different categories.

8. CATEGORIES AND CHARACTERISTICS OF THE CURRENT AVAILABLE WEB SERVICES FOR CONSTRUCTION

The portals that have been launched in the construction sector in Spain, generally fall into four categories
− electronic brochures
− e-commerce portals
− project collaboration services, and
− full service portals

8.1 Portals based on electronic brochures

Portals based around manufactured products form the majority of existing portals. In general they tend to duplicate paper-based catalogues, in several cases to the extent that they scan paper-based catalogues to provide their service. The benefit of this approach is fairly low; the only added benefit over a paper system (assuming that speed of access to information is fairly comparable) is that updates are immediately visible to all users. The presence in Internet is reduced precisely to this; only bring together corporative information of the services that they offer offline.

Table 1. Examples of portals based on electronic brochures

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<td>Construcnet</td>
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<td>Construplaza</td>
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<td>La Nave Industrial</td>
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8.2 E-commerce portals

Some portals are enabling e-commerce for purchase of selected products, and a very small number are providing for selection of products based on their performance attributes. To augment these services the portals often tie in a selected set of related information services, for example, links to Standards, industry news, databases of selected professionals in the industry, etc. A major criticism of these sites is that they lack comprehensiveness. This is often true even for their major information content (i.e. manufactured products), but more especially true for their associated services, which tend to have a minute portion of the information available to the industry.

Table 2. Examples of on-line e-commerce portals

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<th>E-commerce portals</th>
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<td>BravoBuild España</td>
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<td>Construplaza</td>
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<td>Obralia</td>
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8.3 Project collaboration services

Project collaboration services focus on tools and services that make it easier to manage the AEC design projects. Common services include backing up files, keeping a document revision history and tracking who accesses what files. Such sites also offer online document viewing, online markup, and plotting.

All existing web-based project management software are based on exchanging and sharing documents. Information can be stored in a single database where users can view, track and manipulate as and when required.

Currently, there are many commercially available software to cater for different types of document-based data exchange. They all come under the umbrella of web-based project management. These software cater for the application needs of the different stages of the project life cycle: i.e. the tender stage (when tender documents are exchanged between clients, contractors, subcontractors, etc.) and the design and construction stages, (where drawings and other documents are exchanges between project partners), and the construction stage (when buying and selling of building materials take place over internet).

Different collaboration services are being used over Europe: ProjectNet (Bidcom), ProjectCenter (Bricsnet), ProjectsOnline (BuildOnline), ProjectPoint (Buzzsaw), etc.
Some of these services run in Spain but they don’t have national support like ProjectsOnline, ProjectNet, etc. There are other project collaboration services that run in Spain and have also national support like Bricsnet and Structuralia. Many big companies in Spain, like Fomento de Construcciones y Constratas, IDOM, Bobis, etc., have created their own Intranet for the management of their projects.

Table 3. Examples of portals based on project collaboration services

<table>
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<th>Project collaboration services</th>
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<td>ProjectNet</td>
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<td>Bricsnet</td>
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<td>Structuralia</td>
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<td>BuildOnline</td>
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</table>

8.4 Full service portals

In addition to project management tools, full-service portals provide services such as community forums where you can chat with other project managers and share knowledge resources. Other services may include online catalogs for finding materials and subcontractors. This portals based around project information management provide a service to industry by enabling virtual teams to be formed from all participants in a project where project documents are shared between participants in a very immediate fashion. These portals also tend to offer associated services along the same lines as the manufactured product portals and with the same deficiencies.

In the next table, there is a list of portals based on the management of construction projects that are available in Spain at the present.

9. THE FUTURE

The online service industry will continue to solidify, and as time goes by the two main hosting service types—project collaboration services and full-service portals—will likely blend into one.

Managing AEC projects online is growing in popularity. As these services mature, the tools and features offered are refined to meet the most common needs.

10. CONCLUSIONS

The construction sector in Spain has a very suitable characteristics to get profit from the possibilities that Internet offers for the management and basically for SMEs, whom the electronic commerce can help them to increase their competitiveness in the market and reduce costs.

There are more than 270,000 construction companies in Spain and 80% are SMEs with less than 6 employees.

Nevertheless, this possible market is not only to offer tools and platforms for electronic commerce but also to help the management of the whole construction process trying to integrate all the stages and all the participants.

Internet can reduce distances, facilitate communication and collaboration, etc. but all this benefits are conditioned by the other implicated parts that must be prepared to redesign their business.

11. REFERENCES


Gilarranz, L. 2002. La construcción entra en Internet. *Expansión directo*


SEDISI, 2001, Study of the level of IT
The Development of e-Hub Supply Chain Management Portal System for Construction Projects

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ABSTRACT: Construction projects are composed of a large number of contractors, subcontractors, and suppliers that comprise the project supply chain. Construction supply chain management as a field of study concerns itself with improving the coordination of these firms to improve project performance along various metrics such as speed, cost, reliability, quality, etc. In order to link the construction supply chain well, information sharing is a basic requirement and function in the supply chain management system. Without the information sharing, the supply chain partners cannot communicate each other and connect construction operation to synchronize and streamline all communications among the company. However, the rise of the interconnectivity between different information systems over the Internet impacts construction processes, thus the defective characteristics of the construction industry can be overcome by an assistance of technology. This paper describes the prototype and system of e-Hub Construction Supply Chain Management (eHub-ConSCM) System for information shared service in executing the construction projects. The information needs for eHub-ConSCM System are illustrated, a general system architecture is describe and the implementation of eHub-ConSCM system is presented.

KEYWORDS: Supply Chain Management; Information Sharing; Construction Industry

1. INTRODUCTION

Supply chain management is one of the leading business process re-engineering, cost-saving and revenue enhancement strategies in use today. The Internet has already had a tremendous impact on the field of supply chain management, and there is more to come. However, it is not easy to develop a formalized SCM system in the construction industry because production line is changed with every project. Usually, a general contractor is the main coordinator in the construction processes involved many participants and with complicated interface each other. Therefore, it is necessary and important for a general contractor to build a Hub-oriented information center to collect and manage the newest updated information and data from other project-related participants. In practice, interactions among participating project teams are limited only to closely related teams. This is because it is almost impossible to communicate with dozens of subcontractors, suppliers, and hundreds of sub-suppliers in a single project. Furthermore, since all participants have their own competing goals and objectives, the lack of coordination and information sharing among them leads to the distorted demand fluctuation known as the “Bullwhip effect”. Such fluctuation could result in poor project plan and management, excessive inventory, insufficient or excessive capacities, uncertain production planning, and high costs for correction such as for expedited shipment and overtime. In order to avoid the mentioned problem, a hub-based portal system is presented and developed to avoid the problem happened by integrated supply chain management concept and advanced Internet technologies.

2. PROBLEM STATEMENTS

The application of supply chain management for the construction industry is more difficult than other industries due to its own unique characteristics. When considering the traditional fax/phone communication among the participants, the complexity and difficulty of information
exchange is evident. In the traditional construction supply chain, there are many separate material flows and information flows. Each of these flows is charged with making forecasting and production and ordering decisions based on the downstream demands, internal capacity and upstream constraints in the chain with which it interfaces. Because of an inability or unwillingness to share information, the demand signal is often distorted as it flows upstream leading to a phenomenon known as the “bullwhip effect” (Lee et al. 1997). Procter & Gamble first coined the bullwhip effect during a replenishment pattern study for disposable diapers (Nahmias 1997). Procter & Gamble noticed that even though diaper demand was relatively stable, the upstream orders were amplified. In construction, variability increases upstream in the supply chain as each node creates its own forecast, schedule, inventory decision and material requirements plan. This effect is compounded by the fact that ordering is typically based on the immediate needs of the downstream customer. As a result, manufacturers and suppliers carry far more inventory than necessary. By limiting coordination to tradition communication, the supply chain is unable to flexibly meet the demands of the end customer. Effective operational control of a supply chain requires centralized coordination of key data. For construction industries, this typically has meant forecasts, inventory status at all sites, backlogs, production plans, supplier delivery schedules and pipeline inventory. In other words, supply chain integration requires all participants in the network to communicate and share detailed, current information.

3. SYSTEM DESIGN AND ANALYSIS

Information technology can help to overcome the traditional construction supply chain problems. Electronic exchange of information leads to reduction of errors and increased efficiency of the operation processes. When all participants can analyze their projects based on the information sharing from related-participants in the supply chain, the negative effects of uncertainty can be mitigated in theory. In practice, however, the exchange of information between participants is not as easy as it seems. Many different systems and standards are used, the number of peer-to-peer relations with other participants in the network is usually too large to manage, most systems are not open for easy exchange of information with other systems. Furthermore, most participants are very reluctant to share information with other participants in the first place.

A portal represents a solution to overcome these problems. Standardized interactions with one portal are easier to manage than are many peer-to-peer relationships. The portal provides an organization with a single, unified database, linked across all functional systems, both within the organization and between the organization and its major supply chain partners. This paper aims at addressing the quick respond supervision and environment special for general contractor, subcontractors and their suppliers, presenting a web based solution as a support. We present Hub-based construction supply chain management portal system to provide all project-involved participants to provide information sharing service and data center management. Finally the effectiveness of a Hub-oriented SCM system is verified based on the survey by users.

4 SYSTEM IMPLEMENTATION

Increasingly, all the project participants understand the importance of information sharing during the project implement. A major objective of this paper is to illustrate the application in the construction supply chain and explain the framework to link the whole supply chain across all participants, integrated Internet technologies. The portal uses middleware technology to integrate disparate sources of information from participants. Also, the portal provides a secure intelligent online gateway with access to multimedia collaboration functions. With the portal and its associated tools, managers and engineers of each participant can conduct effective monitor and controlling activities for the project. The presented system showed how the designed analysis modules in the Hub-ConSCM portal system could be applied in the construction supply chain industries. The main benefits of using this system include improved the decision-making performance, inventory availability and reduced life cycle costs by providing the right information to the right people to make the best decisions in real time updated situation. The portal solution uses middleware to link systems and participants together and to create a seamless supply chain for system users while hiding the transactional level processing complexity from them. In order to make the system more effectively, the system is designed and developed the three layers. They are the Portal Layer, the business logic Layer and the Data Access Layer (see Fig 2). After the user
logging in, user is taken to the respective interface wherein information is classified under sections of ‘Company Info’, and the related entity. The architecture used is a three tiers model, with HTML, JavaScript / servlets forming the user interface (presentation layer), the connection layer (JSP / JDBC) (Business Logic Layer) and the SQL RDBMS forming the Data Access Layer.

4.1. Presentation Layer

Presentation Layer is responsible for the presentation of data, receiving user events and controlling the user interface. HTML/DHTML with JavaScript is used for developing User Interface Screens. Furthermore, Uses Socket class to communicate with server and Client side validations are done through JavaScript.

4.2. Business Logic Layer

Business logic layer is created using ServerSocket class. It keeps listening for the clients to communicate with it for service. Every time a new client logs on, a separate session is created for processing its The following modules are developed in the Business Logic Layer (see Figure 2):

1. Project control module
2. Project Information module
3. Resource Management
4. Tracing Management
5. Information Analysis
6. Inventory Management
7. Administration Management

The description of each module is summarized in the Table 1. These function modules are special designed for the characteristics of construction projects.

4.3. Data Access Layer

Data Access Layer tier is responsible for data storage. Relational database systems and MS SQL 2002 is adopted in the system. All the changes to the database occurs after the exceptions are caught, handled and confirmation for changes received. Also, System is developed to backup the system Database automatically whenever required.

5. CONCLUSIONS

The Hub-SCM portal system is developed to manager and control the project for the project-involved participants in the hub-center based environment. The Hub-ConSCM portal system allows more effective management of the construction supply chain by providing the information sharing services to project-involved participants and allowing the links of the supply chain to work together to produce the best possible outcomes (see Figure3). The portal system also allows participants to have access newest information and make right decision in their own office without using traditional communication ways. Most important, the portal supports the analysis function for all participants that can use these function directly on the web platform. This allows more complex, integrated decision-making than is possible with separate systems that are, in effect, islands of information. Finally, the system is scalable, allowing more users to be connected as required. This system is applied in the Taiwan real case to evaluate the practice suitability. Interview feedback with general contractor and participants are summarized to modify further system functionality and prototype. The main benefits of the system based on the interview feedback are following:

1. Improvement in the data consistence
2. Faster response and faster trading cycle
3. Maximize business process efficiency
4. A proven track record in SCM
5. Reduce inventory costs
6. Increase visibility and control
7. Automate workflow & information exchange
8. Increase resource utilization
9. Enhance partner communication

6. RECOMMENDATIONS

In the future, internet-based technologies such as XML data formatting and peer to peer system architecture will be considered to use in the system for multilateral collaboration among networks of suppliers, subcontractors, and general contractor in the construction project. Also, the whole data source in eHub-ConSCM system should be integrated with ERP (Enterprise Resource Planning) system. It is necessary and important to connect the two systems together for enterprise information backbone.

7. REFERENCES

Department of Industry, Science and Technology, Australian Commonwealth Government.


### Table 1. System Function

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<th>Category of Modules</th>
<th>Description of Modules</th>
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<td>Project Control</td>
<td>Participants to trace the project-related activities in schedule control. Participants can check and analyze the schedule information by the web-based portal.</td>
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<tr>
<td>Project Information</td>
<td>Participants to download the project-related information (drawings and specification) directly on the web. Furthermore, these project-related documents and information can be contained and updated centrally.</td>
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<tr>
<td>Resource Management</td>
<td>Provide the general contractor to trace and manage the project-related resources using in projects. Users can check and understand which resource is available to use and make reservations directly on the system.</td>
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<tr>
<td>Tracing Management</td>
<td>Provide the general contractor to trace the project-related activities or resources in the project production and deliver process. Participants can enter and update the production information to share the information with other participants.</td>
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<tr>
<td>Information Analysis</td>
<td>Provide the general contractor to analyze the project-related supply condition situation based on the information shared from activity-involved participants. Participants can check the information by the web-based portal.</td>
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<tr>
<td>Inventory Management</td>
<td>Provide the general contractor to trace the project-related materials and elements in the portal. General Contractor can check and manager the inventory status provided by site engineers.</td>
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<tr>
<td>Administration Management</td>
<td>Provide the administrator to control the project-related participants to use this system. Participants can apply authority directly from the portal.</td>
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</table>
Figure 1. System Concept and Framework.

Figure 2. System Architecture.
Figure 3. The Framework of Construction Supply Chain Management.
A model for Construction Project Management extranets

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ABSTRACT: In AEC each participant of a construction project (designer, the constructor, etc) takes part in many other projects and each of these groups of participants are probably working in collaborative spaces. What happens then, when for instance the designer must hold as many collaborative spaces as projects he carries on? In the construction sector, each project is unique and the group of people, who are working on it, is different. Among the drawbacks of several of these applications is the lack of support provided to users. In this Paper a draft of guidelines for the users of extranets for the management of construction projects will be exposed. The aim of this project is to establish the necessary basis and criteria to facilitate an integral project management and to help SMEs using Information and Communication Technologies so as to reduce the fear to this new tool from such a traditional and fragmented sector.

To do so, we have developed a new working and organizational standard model for the information and communication system for the company. The scope of this project is that all the companies (specially SMEs of the construction sector) were capable to identify their necessities, define their process improvement strategies (using ICT) and learn in a reliable way the benefits of using this new technology. In contrary, in an early future this technologies will become an absolutely critic barrier for this companies to participate in many projects. This model will serve as a demonstration for all the participants of a construction project (architect, constructor, client, suppliers, etc.) that all the information functions (consult and storage), communication, data transmission, etc. related to an specific project can be done by using new technologies (like extranets or collaboration tools) and with more advantages than the traditional working methods.

KEYWORDS: guidelines, extranets, document management.

1. INTRODUCCIÓN

AEC (Architecture, Engineering and Construction) firms tend to be involved in a portion of the building process. They team up in different combinations for different projects. AEC firms typically have far less optimised work processes, and they have invested far less in computer technology. However, the final product (a building or a plant) requires ongoing management that is affected by the quality of the information provided to run it. Internet collaboration tools can affect a significant paradigm shift in AEC by unifying the disparate project teams of architecture, construction and owner/operator for the first time ever. Extranets, or collaboration tools, can act as a breeding ground for true integration between discrete processes of all major participants in the industry, by themselves, they may save only a small portion of efficiency throughout the entire lifecycle of a building, but they are a critical first step for our industry to begin truly integrating data such as legacy, and in-house applications and systems. (Weisberg, S, 2002)

Successful online collaboration requires that all project team members— including clients— understand how to use the technology, are comfortable with it, and actually use it to manage projects.

2. THE EVOLUTION OF DOCUMENT MANAGEMENT

The effective management of all the information needed for a construction project from the conception stage to the construction and maintenance of the building is a basic requirement for the success of the project. All participants of construction projects know the impact on overall construction costs of delays, missing or contradictory information, mistakes, etc. Documents in the construction sector have not undergone major changes since the middle of the 20th century. Plan drawings, bills, specifications, etc. look as they did some decades ago. The technology for producing, managing, duplicating
and distributing such documents has, however, undergone a number of fundamental changes. (Björk, 2001)

Firstly, the introduction of photocopying in the 60’s that reduced the cost of duplicating information. Afterwards, the introduction of personal computing for the day-to-day work during the 80’s and the mass utilization of CAD-systems, word-processing and other software helped to reuse information.

In the 80’s the fax became also a popular data transfer method and was used to handle offers, send graphics, etc. but was not useful for larger drawings or documents.

Finally, in the late 80’s and early 90’s Internet made possible the document transfer via mail that was a great step for the document management. Currently, it’s nearly 10 years from the beginning of the mass commercialisation of Internet, the media that has progressed in an exponential way.

In its original form, the Internet was used to show information, and send information via mail. It was an important advance in document management and communication among partners but other important requirements in the construction management projects were still not addressed. This speeded up the document transfer, but in terms of document management, this hardly offered any improvement over the current situation since finding a document in another person’s PC may be even more difficult than finding it on his shelves. Finding a document may often as a last resort require asking a person to deliver it.

The evolution tended to join communities of users, professionals, etc. in different spaces that were called Virtual Communities and Portals. A portal is ‘The web page where to aggregate contents and functionalities, organized in a way that facilitates the navigation and gives the users an entrance to the Net with a huge range of options’. Therefore, users have the services and products of an area of knowledge that might need all together.

Later, companies felt the necessity to offer services and improve their contents. Now, the strategy of Internet is not only to ‘be’ there but also to ‘do’.

Not only after some years of the beginning of the first portals, the construction sector entered in Internet.

The most sophisticated method currently in use is to use extranets or document management systems where the documents are stored centrally on a web server and users interact with this central repository though interfaces implemented using standard web browsers. (Björk, 2002)

Many different names have been used by both service providers and researchers to denote such systems, including Document Management System, Project Extranet, Project web, Project Bank, Project Specific Web Site, Document Pool, Project Information Management System, and Virtual Project. Some authors give these terms slightly different meanings. A project specific webs site (T. Thorpe, S. Mead 2001) can, for instance include quite a lot of general information about a building project (i.e. live web cams) in addition to the basic Electronic Document Management functionality.

3. ORGANISATION STANDARD MODEL

The growing number of international projects and widespread adoption of project management leads to a significant increase in the number of individuals across the world that need to communicate within and understand the field of Project Management.

In the construction sector, most of the projects are developed by many different partners who are often geographically dispersed and have to coordinate their activities. They need to exchange information electronically; to be connected to a controlled-access web-based workspace, in order to share data and information; to create structured electronic databases; to provide information and products and services electronically; to interact with customer and provide fast and effective online assistance, etc.

There seems to be some disagreement about the levels of participation and interest by the three main groups comprising AEC: designers (architects and engineers), contractors, and owner operators/clients.

But the main problem is how each participant deals with his data and how can the management of his enterprise can be compatible with the management of a project. (Burchard, B, 2001)

There is a clear need of a framework that enables all parties to communicate and exchange information via IT.

If construction organizations are to benefit from IT investments, then new guidelines for Small and Medium Enterprises are required such that construction business participants can understand and feel fully confident in applying them.

Therefore, it’s necessary to have a common basis for all organizations due to the possibility of each
organization to be involved in many other projects. These guidelines should be focused on the contents of the system so as to improve the actual management of each organization and to increase the efficiency of the team as a whole. On top of that, some organizations have already implemented some Management Systems according to ISO 9000, ISO 14000, OSHA 18000, etc. so it’s obvious that these guidelines should not be against these norms. They should complement them.

If this kind of framework exists, the online services industry will continue to solidify and services providers will be compelled to adjust their offerings. (Forcada N. et al, 2002) Guides and/or standards can also be seen as a way of making the tacit explicit by formally documenting the accepted ‘best practices’ of practitioners in order to make them more readily transferable to novices.

3.1 Background

Some of the characteristics of the construction sector are:
- specifications for design and manufacturing in all disciplines is of major importance,
- there is a need for understanding globally, utilizing a common communication language;
- the use of computer aided systems prevails, e.g. CAD, CAM, PDM;
- the tendency for use of sub-contracting, outsourcing and consultancy is increasing;
- the quality management systems according to the ISO 9000-series (including supporting standards) is of high priority to all industries;
- the technical product documentation may be regarded as a basis for contractual interpretation.

All these restrictions make necessary a standardization and coordination of information throughout the product life cycle to facilitate preparation, management, storage, reproduction, exchange and use of this information.

3.2 Expected benefits

Implementation of a guide for project document management:
- reduces costs;
- assures quality;
- implies shorter elapsed time from design concept to market product;
- provides a platform for communication;
- reduces the risk of misinterpretation.

The increasing utilization of Information Technology (IT) within technical product documentation has highlighted several new topics, of which the following have been identified as being of particular importance:
- classification;
- meta data;
- document management data;
- document technical contents;
- product modelling.

We are focusing on the first three characteristics to solve part of these problems.

3.3 The Process to create an organizational Standard Model for document management

3.3.1 Mapping participants and processes

This guide is intended for use by all those involved in the construction project: client, design consultants, contractors, sub-contractors, suppliers, control laboratories, etc. but the current extranets that are in the market are focused on the monitoring of the project.

![Figure 1. Participants of a construction project](image-url)
operation for the construction of buildings and is widely accepted as an operational model throughout the building industry. It represents a logical sequence of events that should ensure that sound and timely decisions are made. The phases and stages that have been chosen to map all the activities and documents to be transferred are:

- **Pre-design phase**
  Throughout the Pre-design Phase the client’s need is progressively defined and assessed with the aim of determining the need for a construction project solution.

- **Design phase**
  In this phase the defined client’s need is developed into an appropriate design solution. At the end of this phase, the aim is to secure full financial authority to proceed.

- **Preparing to build phase**
  This phase is based on producing the final information of the project and the tendering.

- **Construction phase**
  It is here where the full benefits of the co-ordination and communication earlier in the process may be fully realized. Potentially, any changes in the client’s requirements will be minimal.

- **Post-construction phase**
  Upon completion of the Construction Phase the process continues into the Post-Construction phase, which aim to continually monitor and manage the maintenance needs of the constructed facility.

Once we had mapped all the participants of the process of a construction project and all the phases and stages, from these information we generated a matrix to create a friendly and easy to understand organization of the contents. The next figure shows the basic organizational matrix.

![Figure 2. Basic matrix to access the guide information](image)

From each PHASE and STAGE we have defined all the documents, which will be produced in those part of the project. The main characteristic was to define the most important information of each document so as to have the whole relationship among all the related information. From each document we have defined a set of metadata.

### 3.3.2 Document metadata

In common language the word document usually means a container of information (usually on paper) containing written or drawn information for a particular purpose in a structured way. Traditionally, a document is a piece of paper or a collection of papers, for instance, a memo, a letter, a mission statement, a bill of materials or a customer invoice. The paper presented information, usually text or text and graphics, is laid out on physical pages.

Over the last decade, the term “document” has undergone a radical change in definition. In part, this change is due to IT. Information technology is now capable of producing a new electronic document, which can house graphics, text, CAD, and multimedia objects, (i.e. audio or video clips). Documents are processed and stored in electronic form, not as physical objects, but as digital ones. The document is no longer the place where words are put on a page, but rather a collection of elements or objects related to a particular topic, brought together. Therefore, a new definition of a document in electronic age emerges.

An Electronic Document is an information container in electronic form, which gathers together information from a variety of sources, in a number of formats, around a specific topic to meet the needs of a particular individual. A user can create an electronic document on a personal computer without creating a paper document. An electronic document can be identified, taken and stored from Internet, Intranet and Extranet in an electronic manner. A single electronic document can be processed and transmitted to others on networks at the same work place or even by users around the world via Internet. The document in an electronic document management system is really an electronic object since it is neither a piece of paper nor a film.

One advantage of the electronic document is that it is not necessary to have the same media for every user. An electronic document can be delivered in any format that meets the needs of user.
Central to the idea of a document is usually that it can be easily transferred, stored and handled as a unit (Löwnertz 1998).

After a brief description of the document concept we are able to categorize and define metadata for each of the electronic documents generated in the whole life cycle of a project.

Electronic documents can be categorized according to different purposes:

<table>
<thead>
<tr>
<th>DOCUMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document name:</td>
</tr>
<tr>
<td>Description:</td>
</tr>
<tr>
<td>Late submittal date (phase):</td>
</tr>
<tr>
<td>Author:</td>
</tr>
<tr>
<td>Reviewer:</td>
</tr>
<tr>
<td>Modifier:</td>
</tr>
<tr>
<td>Reader:</td>
</tr>
<tr>
<td>Users:</td>
</tr>
<tr>
<td>Type of document:</td>
</tr>
<tr>
<td>Attributes:</td>
</tr>
<tr>
<td>Related documents:</td>
</tr>
</tbody>
</table>

**Figure 3. Metadata assigned to each document**

For each document we have defined the next set of metadata:

**Document name**
Each document name is formed by 2letters+3numbers+4letters+4numbers. The first two letters concern to the name of the project. The first three numbers concern to a consecutive relation of documents with the same characteristics. The following two letters concern to the initials of the attribute of the document and are written in capital letters. The last two letters concern to the initials of the type of document and should be in small letters. The last four numbers are the latest publication, revision or modification date. The first two numbers are the year and the others are the month. For example, if we have a Site Note of the Forum project that was modified on the 3rd of November 2002, its document name will be: FO001SNdc0211

**Description**
It depends on the author necessities. It can be notes for a better understanding of the document or a global description of the document.

**Late submittal date (phase)**
The late submittal date is the phase (design, construction, etc) and stages (inception, feasibility, etc.) when the document must be submitted for the right functioning of the project.

**Actors:**
The author is the person who has created the document and can view, upload, create and delete the document. Reviewer: the person who has the right to review the document and can view and upload it Modifier: the person who can modify a document as well as view and upload it. Reader: the person who has access to the document so he can view it. Users: the person/s who will need this document for the completion of the project. For example the document 003PADw0301 an architecture drawing of the project, should be submitted about the middle of the design phase and by the middle of the detail design activity. The author of this document will be the architect and the civil engineer will use it during the design phase. These attributes might change along the different phases of the project. At the beginning all the drawings will be used by the designers but once in the construction phase the contractors, suppliers, etc. will use them so we should define an attribute relating the information of each partner to the stage or phase when they need the information called ‘Phase reader’.

**Type of document**
The format of the document is included in this information. If it’s a word document, an excel document, an AutoCAD document, etc. The different types of documents are: word, excel, access, power point, winproject, CAD, image, web, e-mail, etc.
dc: word DoCument .DoC
xl: eXceL document .XLs
md: access document .MDb
pp: Power Point document .PPt
wp: Win Project document
dw: DraWing document .DWg
im: .IMage drawing .gif, .tiff, .jpg, bmp
hm: web document .HtMl, .HIM

**Attributes**
We can classify each document depending on the stored information. The attributes can be:
SN: Site Notes
ME: Meetings
CO: Change Order
RE: REports
RI: Request for Information
CT: ConTract
BD: BuDget
CM: Cost Management
P_: Project
PA: Project Architecture
PS: Project Structures
PM: Project Mechanical
PE: Project Electrical
PQ: Project Quality
PS: Project Health and Safety
PE: Project Environment
PP: Project Planning
PS: Project Specifications
LE: Letter
RC: ReCeipt
IN: Invoice
TS: Technical Specification

Related documents
Set of documents that are needed for the entire understanding of it. For example a related document of a Request for Information might be the drawing that we are asking for.
The related document of: FO005RIdc0302 might be: FO024PAdw0211.

3.3.3 Guidelines
After mapping all documents to be transferred and all the communication among all the participants in each phase and activity of the project we proceeded developing a set of guidelines to help SMEs archiving their project information so as to use a common framework when working with construction extranets.
It’s a generic and global model for whatever construction project.
These guidelines are defined for the entire project and for all the stages.
The main purpose is to have all the information related to one actor so as he has the following data:
• When to deliver a document
• Who will deliver the document and when will it be delivered
• Compulsory communications to make

4. CONCLUSIONS
New technologies have changed the way of working in many sectors and the last decade the construction sector has also started to notice this influence. Many businesses related to construction have started to use extranets and/or cooperation portals but the lack of standardization of the processes makes it more difficult to deal with.
The basis and criteria to facilitate an integral project management and to help SMEs using Information and Communication Technologies that we are exposing will reduce the fear to these new tools from such a traditional and fragmented sector.
Once these standards are accepted, the adoption of information technologies will be deepened, construction business processes will be streamlined, construction markets will be expanded, and construction technology will be improved. To facilitate the benefits provided by systems, owners and constructions must, respectively, restructure their organizations for better competitive positions. The restructuring will be both intra and inter organizational.

5. REFERENCES
Bjork 2001, Document management –a key IT technology for the construction industry, ecce conference
Burchard, B, 2001. AEC Project Management ONLINE. Cadalyst
E-Business in the construction industry: 
a search for practical applications using the Internet

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ABSTRACT: New technology often drives organisational changes. The influence of Information and Communication Technology (ICT) on modern business is enormous. ICT not only supports improvements in the primary process but, for example, also enables better planning and much improved logistics. Here communication technology is equally or even more important than information processing itself.

In the current economic downturn, the construction industry will be forced to answer to the ever-increasing customer demands for flexibility both in relation to the end product as well as to the construction and production process. Construction companies need to anticipate these new requirements. A complicating factor in this context is the way the construction industry is organised: many companies with varying expertise, working on a project base together, all contributing their own - often small - part to the end product. This makes the use, and above all the efficient use, of ICT in the whole construction process difficult when we try to tackle the subject of collaboration: all participants are confronted with slightly different ways of working which make the exchange and reuse of information difficult. To be able to manage communication, co-operation and collaboration, the Internet is already playing an important role.

Internet technology can be the source of many improvements. Initiated amidst the e-Business hype, the project Digibouw has resulted in an overview of seven concrete functional areas where the Internet may provide the construction industry with the technology to improve performance. In this paper we present the findings of this research and focus on the area of e-Procurement, and specifically on one of its aspects, e-Ordering. We will show not only what it can bring to a single company, but also offer some advice on how to start introducing e-Ordering.


1. INTRODUCTION

In 2000 the DigiBouw project was started as an initiative of VGBouw, an organisation of larger construction companies in the Netherlands. The objective was to investigate the (practical) use of e-Business solutions in the construction industry [Wamelink-2003].

The various participants in a construction project traditionally have a pragmatic approach towards new technology: it should be convenient to use and bring convincing advantages when compared to current common practice.

Given this down-to-earth attitude and the well-known hype surrounding e-business, people are suspicious of internet solutions. This paper describes the results of the DigiBouw project, with a special focus on e-ordering. The next sections describe not only the possibilities of e-business in construction, but also how to implement them.

The first section describes the meaning of e-Business in general. Then the e-Business application areas important to the construction industry
are examined in more detail. To illustrate the meaning and consequences from E-business in practice, section 3 focuses on one specific area: e-ordering. Finally, conclusions are drawn and a general approach is offered for starting to use e-Business solutions in the real world.

2. E-BUSINESS

The term “E-business” is defined as the use of information and communications technology to change and improve business relationships [Hartman]. The “business relationships” referred to are not only limited to those between the business and its customers, suppliers, etc., but also include those with employees and governmental institutions.

With respect to the technology part of the definition of e-business, the Internet is an important enabler, giving a host of new possibilities. Literature (see for instance [Hartman]) describes many advantages. Examples are the strengthening of relationships with customers (termed “customer relation management”) or increasing their market. Process efficiency improvement is also often quoted.

2.1 E-business in the construction industry

The benefits of the Internet also can be applied in the construction industry. Many researchers point at the need for construction organisations to make the necessary investments that will enable them to take advantage of the new technologies available [Anumba] [Brandon]. During the Digibouw project, research was undertaken to investigate which functional e-business areas can be truly relevant mainly to construction companies.

Possible e-business applications can be divided into three main groups (see also figure 1):

1. e-business applications supporting communication processes with the customer/principal (e.g. concerning design information)
2. e-business applications supporting communication processes on the purchasing side of the company (concerning information about contracted out supplies)
3. e-business applications supporting internal processes within the construction company.

2.2 E-business in relation to the customer

In fact this is the sales side of the construction company. In this case e-business can improve the relation with the principal. Examples of using the Internet are: gathering customers’ expectations (principal, tenants); providing information about the progress of the building process; handling complaints; creating and operating a helpdesk, etc.

Specifically in housing the Internet can be used to facilitate communication between the customer and the contractor about changes in design.

Electronic support in the form of project webs, optionally with workflow functionality, will lead to a better control of the whole process and will result in less confusion and disputes because of missing and failed communication.

2.3 E-business in relation with suppliers

At the purchase side of the construction company relevant e-business areas are E-procurement (including e-ordering) and E-tendering. E-procurement is examined in detail in section 3. E-tendering concerns the support of the subcontracting process. After placing the tender information on the Internet, potential subcontractors can subscribe to the bid. Advantages are enlargement of the market range and aggregation of different tenders, which will lead to lower costs.

2.4 E-business supporting internal processes

E-business is often connected with communication between different companies. As seen in the definition of E-business (see section 1) internal applications are also part of this definition. Each com-
pany always searches for the most effective and efficient processes to reduce costs (of failure). In other words: improvements in integration and management of (internal) processes. In this area the application of ICT can be of great interest. Examples of E-business concerning internal processes are knowledge management, document management [Björk] and workflow management [van der Aalst] [Wamelink-2002].

Besides this, the intense use of ICT within the firm itself is an important precondition to implement the applications supporting communication between companies.

2.5 Summary of relevant e-Business application areas

In the preceding section seven relevant examples of E-business in the construction industry are given:

- Projectwebs
- E-procurement (including e-ordering)
- E-tendering
- Knowledge management
- Document management
- Supporting the principal
- Approaching the individual customer

In the Digibouw project these areas are mentioned as potential contributors to major improvements within construction processes and projects in general. To demonstrate this contribution to improvements, the next section describes one of the above application areas (e-ordering) in detail.

3. E-ORDERING

3.1 Definition

What is e-Ordering? Simply put, e-Ordering is calling-off supplies based on an agreement that was reached earlier between the construction company and the supplier.

Consequently e-Ordering does not involve finding a supplier or determining a price; nor closing the contract. In fact it is everything that follows after the contract has been signed:

- Determining the batches and setting their preliminary date of delivery;
- confirming that date, possibly modifying some of the details;
- ordering the supplies so that they arrive just in time;
- verifying the shipment for completeness;
- invoicing and payment.

3.2 The benefits

So where are the benefits of e-Ordering? Currently, the process of ordering:

- requires significant administrative book keeping by the foreman on site
- is error-prone due to the fact that orders are generally taken by telephone;
- incomplete deliveries cause delays and more importantly ‘improvised buying on site’ causing uncontrollable prices;
- the process comprises several points at which (sometimes the same) data has to (re) entered;

The process of e-Ordering should solve all of these problems. This is accomplished by moving all the administrative tasks to the project administration (who may be on site or not), and offering the ‘foreman’ ordering capabilities at the push of a button. This need not involve all kinds of fancy software, but could just mean a well-prepared paper order form supplied by the project administration and drawn from the existing detailed project plan. This form is (for example) faxed or e-mailed to the supplier (referring to previously made agreements) so errors are reduced to the minimum. Upon delivery, the supplies are checked against the order, differences noted, and payment can proceed (possibly even without an invoice present, because a contract was already drawn up at the start of the project).

In the Digibouw project, a calculation of the Return On Investment (ROI) was made for the housing division of a large construction company. Table 1 shows the parameters, used as starting point to determine the ROI.
Table 1: parameters used to calculate ROI

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total spend a year</td>
<td>€ 75,000,000</td>
</tr>
<tr>
<td>Number of suppliers</td>
<td>2,600</td>
</tr>
<tr>
<td>Number of call-off orders a year</td>
<td>20,000</td>
</tr>
<tr>
<td>Number of invoices a year</td>
<td>14,000</td>
</tr>
<tr>
<td>Number of contracts</td>
<td>750</td>
</tr>
<tr>
<td>% bought on contract (before implementation)</td>
<td>90%</td>
</tr>
<tr>
<td>Target percentage bought on contract</td>
<td>98%</td>
</tr>
<tr>
<td>% reduction in improvised buying on site</td>
<td>5%</td>
</tr>
</tbody>
</table>

During the research, the following expected savings were quantified:
- a reduction in administrative work in the logistic and billing process;
- reduction of improvised buying on site
- less errors;
- better procurement contracts (e.g. through additional discounts)

Table 2: savings after implementation e-ordering

<table>
<thead>
<tr>
<th>Component</th>
<th>Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process order efficiency</td>
<td></td>
</tr>
<tr>
<td>Savings on goods ordered purchase orders</td>
<td>€ 84,459</td>
</tr>
<tr>
<td>Cost of goods ordered logistics process</td>
<td>€ 50,676</td>
</tr>
<tr>
<td>Cost of goods ordered billing process</td>
<td>€ 59,122</td>
</tr>
<tr>
<td>Reduction of errors</td>
<td>€ 10,135</td>
</tr>
<tr>
<td>Commercial savings</td>
<td></td>
</tr>
<tr>
<td>Savings by more on contract</td>
<td>€ 30,000</td>
</tr>
<tr>
<td>Percentage discount spend aggregation</td>
<td>€ 187,500</td>
</tr>
<tr>
<td>Savings on paper, fax, mail, etc.</td>
<td>€ 1,000</td>
</tr>
<tr>
<td>Total savings</td>
<td>€ 422,892</td>
</tr>
</tbody>
</table>

The calculated savings form almost 0.6% of the total spending. Taking into account that approximately 70% of total building costs is in purchasing (including subcontracting), these savings result in an extra revenue of almost 0.5% on the turnover.

The total investment was calculated at € 380,000 (including implementation and organisational change). So the payback period turned out to be less than one year. Although a lot of assumptions influence these calculations it is clear that e-ordering will be very interesting for a medium or large sized building company.

The success of e-ordering relies on the quality of project preparation, more than currently is the case. This is because now much is left to the ingenuity, flexibility and inventiveness of the project leader and foreman: dealing with things going wrong: a delayed plan, changing specifications or just plain mistakes. Although this may lead to the desired outcome (the building being built), it always involves higher cost or delays or both.

To achieve this, an organisational change process must be started, involving much more than just the introduction of new technology. This change process is discussed in more detail in the next section.

4. INTRODUCING E-ORDERING

As was made clear in the previous section, e-ordering’s success depends in turn on the success of a major organisational change process. It requires designers, planners and purchasers to plan accurately and to a more detailed level. Beside this they have to record very carefully and in detail.

But more importantly they need to work together (in parallel) to achieve one specific goal: an accurate plan to deliver the desired construction for the desired price and on time. Now, requests for proposal are sometimes sent at three different stages and from three different departments all trying to realise the best price. This can be easily improved upon, but only as long as the responsible department is kept involved throughout the long design and planning process, rather than only at one point.

For the change to have a chance of being successful, a company-wide agreement on the goals is required, together with the commitment to succeed. The latter should be communicated and shown in deed by the entire management. The change requires careful planning, sufficient budget and above all, flawless execution, both in time as in the outcome.
Beside organisational change, successful implementation of e-ordering needs fully integrated information systems and a professional ICT infrastructure to centralise all the information gathered by different departments within the company.

E-ordering can be a first step in several ways. For example on the way to a more efficient and effective procurement process (whether implemented as e- or not). But more importantly, the success of the project may help to create a mood for change. The momentum gained should be seized to start other projects.

5. CONCLUSIONS

In this paper we focused on e-ordering as an area where construction companies may benefit from ICT. The Digibouw research showed that a business case can easily be made for the investment in the necessary organisational change.

However, the research also showed that, to achieve success, e-ordering – and in fact each of the seven relevant functional areas of e-Business – requires more than just the implementation of an Internet-based application. It involves organisational change. Change in the way of working. Change in the relations internal to the (construction) companies; but also external with clients and suppliers.

6. REFERENCES


A construction process model for implementing constructability in construction

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ABSTRACT: In construction, failure of design professionals to consider how a builder will implement the design can result in scheduling problems, cost escalation, delays and disputes during the construction process. The integration of construction knowledge and experience during planning and design is termed here as ‘constructability’. Though many design professionals in the Netherlands may informally apply such concept in their works, most design firms however have no formal constructability programmes or procedures in their planning and design activities.

This paper describes a construction process model that has been developed for an engineering firm in the Netherlands in order to implement constructability as a formal programme during its design processes of urban construction projects. The paper describes current problems in urban construction projects and presents a new design model including a constructability programme. The usefulness of the model is validated using opinions of industry professionals. Conclusions on the usefulness of the process model for improving the design process are drawn.

KEYWORDS: Constructability, construction planning, construction process, design process, process model, urban construction project

1. INTRODUCTION

All parties are required to plan a project and control its operation. A successful project achievement in accordance to planned schedule and budget is of vital importance to the owner, who makes plans and commitments on basis of the project anticipated completion date and cost. Failure of design professionals to consider how a builder will implement the design can result in scheduling problems, cost escalation, delays and disputes during the construction process. The integration of construction knowledge and experience during design is called ‘constructability’.

The constructability concept is introduced in 1986 by the Construction Industry Institute [CII, 1987] and is defined as being “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives”.

Originally, constructability was seen as a concept increasing only the productivity during construction phase. Constructability theory has, however, developed to a project concept that is applicable and that offers advantages during the whole construction process [CII, 1992], [Anderson et al, 2000].

By applying constructability in the construction process, the awareness of decision makers regarding the design or construction process is increased. When several parties become more aware of aspects outside their own professional field, it becomes possible to optimise the overall project goals.

When constructability is applied in a right way, it can lead to more awareness, to more interaction between different parties, principles and standards that improve the construction of the project, to provide better feedback to parties involved, and to improve the learning curves for project members [Griffith et al, 1995], [Jergeas et al, 2001].

Several independent studies have indicated that the integration of construction knowledge and experience in the design process increases...
considerably the chances for a higher quality, safer work methods, achieving the planned finishing day and the execution of the project within the planned budget [Arditi et al, 2002].

Though many design professionals in the Netherlands may informally apply constructability concepts in their works, the majority of design firms however have no formal constructability programmes or procedures in their planning and design activities.

This paper describes a construction process model developed for an engineering firm in the Netherlands that implements constructability as a formal programme in the construction processes of urban construction projects. These projects cope with specific problems that necessitate the integration of construction knowledge and experience in the construction process.

Section 2 of the paper describes the research method and Section 3 describes current problems in urban construction projects. In Section 4, the developed model is described and the framework for integrating the constructability programme is outlined. The last section draws conclusions on the usefulness of the model for improving the design process.

2. RESEARCH METHOD

The main question this research tried to address was “How to integrate construction knowledge and experience during the construction process of urban construction projects?”. The methodology used to help reach an answer to this question involved three major steps.

The first one comprises using interviews to collect information from owners, designers and contractors about current constructability problems in urban construction projects.

The second step involved developing a model for the firm’s existing construction process, using Soft System Methodology (SSM), see [Boardman, 2002]. This method is chosen because, in contrast to Hard System Methodology, it supports modelling of processes in ways that allow the roles of actors in these processes to be taken into consideration. In any construction process, roles of people are of major importance and the results of a construction process depend on the performance of those people. Moreover, different participants of a construction process look differently to problems in the process.

For modeling the design process, the seven steps proposed by Checkland is used, see [Checkland, 1993].

The final step entails proposing a constructability programme, which can be tied to the existing process model in order to produce a modified construction process model that integrates construction knowledge and experience into planning and design. The usefulness of the model is validated using opinions of professionals from the industry. They are asked to critically assess the practicability of the model and to examine its suitability for complex projects.

3. PROBLEMS IN PRACTICE

Constructability problems in urban construction projects can be subdivided into problems related to the environment of the construction site and problems related to the construction activities themselves.

3.1 Problems related to the environment

Construction activities in urban areas can cause a great deal of problems and hindrance to people and the surrounding. This is undesirable in the sense that citizens deserve a nice environment and that this can cause considerable hindrance and disturbance to normal living. Moreover, people can ask for compensations for damages or even attempt to stop the construction activities.

Problems related to the environment can be classified according to the followings:

- accessibility;
- living conditions;
- safety;
- communication.

*Accessibility:* Construction activities in urban areas lead to traffic congestions and re-routing, bad traffic flows and difficult accessibility of stores and facilities.

*Living conditions:* Loading and unloading locations, household refuse locations, letterboxes, tram and bus locations can fall into disuse and replacement locations are not always arranged. Another type of living problems due to construction is the accumulation of dust on the roads.
Safety: Unsafe traffic situations can arise because of limited construction space and the presence of heavy transport activities. Loading and unloading of construction materials outside the construction site can undermine safety. Pedestrians enter the construction site because of unsecured fences around the site. Absence of adequate street lights can also create unsafe situations.

Communication: Communication and coordination are critical aspects of construction activities in urban environment. Plans have to be communicated between all parties involved as well as with people who might be affected by the construction works. When information is not well communicated it may lead to claims and counter claims that can cause delay and result in considerable extra costs. It may also lead to halt of construction activities for a period.

3.2 Construction problems

Besides the occurrence of problems related to the environment of the construction site, there are also problems related to construction and construction site. These can be summarized as follows:
- Construction site layout: there is limited space for storage of materials, loading and unloading and parking facilities for personnel because of limited space in urban areas;
- Ambiguities and mistakes in the builder’s specification and drawings: caused by integrating several items resulting in decreased transparency, made too fast;
- Materials: some chosen construction materials are heavy to handle or to process even under good conditions. They may require specific skilled personnel who are difficult to find. Some materials will also affect planning problems because of long delivery periods.

One of the main causes of the above-mentioned problems is the fact that the different parties who contribute to the realization of the final product operate often as single actors in successive and fragmented construction processes. The parties lack knowledge of aspects outside their own working field and thus do not take into account these aspects in their work. As a result, the overall project is not optimised, but instead only sub products and processes are being optimised.

4. THE CONSTRUCTION PROCESS MODEL

4.1 Model

In order to implement constructability concept in projects it is very important to determine how to effectively integrate construction knowledge and experience into each phase of the construction process. In this work, this is carried out using a process oriented framework whereby it is given when, where and how this integration of the knowledge and experience can take place without hampering the regular construction process. The research provides a framework for implementing constructability in all phases of the construction process. This paper however emphasizes only the framework proposed in the design phase.

The proposed model is designed to be used at a project level. If it is decided at an early stage of the construction process; i.e. the feasibility study phase, to apply the constructability concept, the model suggests the appointment of experienced person as a ‘constructability coordinator’. The coordinator function will be to facilitate the application of the constructability concept and to coordinate the various knowledge and experience within the project with the help of a constructability team.

Part of the developed model is illustrated graphically as shown in Figure 1. The model is based on the present design process used by the engineering firm with additional activities that are designed to allow for the implementation of constructability within the process.

The proposed model shown in Figure 1 can be explained as follows:
- At the top left of the diagram, the preceding phase of the process is described.
- At the bottom right of the diagram, the succeeding phase of the process is described.
- The left hand side line of the diagram running, in between, from the top left to the bottom right represents the model of the present process of the engineering firm.
- The loops of lines on the right hand side of the current process line of the diagram represent the modifications required to integrate constructability and hence the entire diagram represents the new proposed model.
4.2 Integrating standard constructability concepts

In the design of the proposed model, a number of standard constructability concepts are adopted. These imply the followings:
- The constructability program forms an integral part of the overall project plan.
- Initial plans are based on construction knowledge and experience.
- Early involvement of construction experts in the development of the contract strategies.
- Project plans are construction oriented.
- Construction methods are considered during the conceptual design approach.
- Early involvement of project team who is responsible for implementing constructability.
- Application of advanced information and communication technology tools within the whole project.

In addition to the above standard concepts, other concepts are also integrated. These are specifically designed for use in urban projects in order to reduce or eliminate the problems described in Section 3.

4.3 Integrating specific constructability concepts

4.3.1 Problems related to surroundings

**Accessibility:** The purpose of this concept is to improve accessibility from and to the construction site of urban projects. This is done by considering site accessibility problems in the very early stages of the project. In this respect, considerations are given to the followings:
- there is adequate accessibility around the site;
- temporary diversions and facilities are of good quality;
- the use of diversions and routes that are not used by other projects;
- early consideration of materials delivery routes.

**Living conditions:** This concept is used to reduce problems related to living conditions in and around the construction site. In here, considerations are given to the followings:
- temporary measures are taken to replace temporary removed public facilities;
- extra measures are taken to clean, organize and maintain the surrounding of the construction site.

**Safety:** In implementing this concept, the following measures are taking into account:
- construction site and the surroundings are well lit;
- site fences and gates are well secured;
- construction site is well isolated.

**Communication:** This is to ensure good communication between participants involved. Attention points are:
- early communication over planned activities and their effects on the surrounding;
- provision of construction site information boards and telephone numbers for more information;
- provision of a mechanism for communicating problems and complaints from interested parties.

4.3.2 Problems related to construction

**Construction site layout:** This concept is meant to provide more efficient construction activities by providing a better project site layout. The points required considerations are:
- design a site layout to ensure that there is adequate space for materials storage, equipments and construction activities;
- access to materials, equipments and personnel;
- sequence of activities;
- planning of major equipments;
- organizing locations within restricted site;
- logistics for supply and transport of materials to and from the site.

**Ambiguities and mistakes in the builder’s specification and drawings:**
In this area, the following points are taken into considerations:
- draw up the project specifications by people who have adequate construction knowledge and experience;
- providing enough time to draw up complete and consistent specifications;
- providing clarity and transparency of the specifications;
- the specifications are drawn up in such a way as to ensure that the use of state of the art cost effective techniques and materials are considered.

**Materials:** This concept ensures that the opportunity is provided early in the process to exchange ideas between professionals regarding construction materials before ‘design by drawing’ has started. Attention is particularly given to:
- simplicity of the design;
- the use of standard construction elements;
- maintenance of construction elements;
- the usability of materials during unfavourable weather conditions.

4.4 Validity of the model

The applicability, usefulness and relevance of the developed model were validated using experts' opinions through interviews. The experts were asked to assess the model from two aspects: The form of the model and its contents. All interviewees have assessed the form of the model positively. They have indicated that the model depicts the whole process very clearly. It shows what constructability measures are required next to the normal process.

The fact that the model follows the existing process structure is considered by experts as positive and that integration of constructability with the existing process will lead to improvement in quality in the long term.

The experts also thought that the accumulation of knowledge and experience by the constructability team over the various phases will contribute in improving the process considerably.

The model is also seen as a proactive way of integrating the construction knowledge and experience. A number of the interviewees have also expressed concerns about the extra cost of implementing the proposed model. This includes the costs of forming the constructability coordinator and team.

5. CONCLUSIONS

Experience shows that many large construction projects suffer from cost and time overruns. There are also other specific problems related to the construction of large urban projects; problems caused by and to the environment around the construction site as well as to construction.

The research has indicated that many of these problems exist because there are little interactions between the various phases of the construction process and that very limited use is made of the construction knowledge and experience in these phases. It has also indicated that it is possible to use the constructability concept to develop a model that can integrates this knowledge and experience in the existing construction process.

Experts have indicated that the developed model is very useful and that it can be applied for the benefit of improving the quality of both the process and the product.

6. REFERENCES


Construction Industry Institute (CII). (1992), Project-level model and approaches to implement constructability, University of Texas, Austin: CII Constructability Task Force.


Figure 1: Part of the Proposed Construction Process Model
Electronic Checklist of Risk Items on Construction Projects

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ABSTRACT: Risk management in construction encompasses four main phases; risk identification, quantification, mitigation and control. Risk identification has been recognized as the most crucial phase of a successful risk management program. This paper briefly describes a model, designed to automate the risk identification process. The model facilitates the development of an electronic checklist of items that are likely to give rise to risk on construction projects. A risk classification scheme is proposed, where risks are classified as either generic or domain-specific. Generic risks are those which might be encountered on any project, irrespective of its type (e.g. currency fluctuations). Domain-specific risks, on the other hand, are those which are associated with the nature of the project at hand (e.g. risks encountered on transportation projects might not be encountered in hydro projects). At the core of the model is its relational database, designed to store various risk items. The impact of project domain, size, location and delivery type (Engineering – Procurement – Construction vs. Build – Operate – Transfer) are considered in developing an automated list of project-specific risk items. The proposed model is implemented in a prototype software, which operates in Microsoft Windows® environment. It employs Microsoft Access® as the database management system and incorporates a user-friendly graphical user interface, utilizing dialog boxes, menus and toolbars. The developed system has several practical features, including the definition of one or more references to each stored risk item to enable tracking and reviewing of their sources. It provides three levels of access for security purposes. It is flexible, allowing updates and editing of defined project-specific risks.

KEYWORDS: Risk identification, risk management, construction management.

1. INTRODUCTION

The first and most important phase of a risk management program is risk identification (CII 1988; De Zoysa and Russell 2003), as a risk that is not identified cannot be quantified, controlled, transferred or otherwise managed. The process is particularly difficult as there are no structured methodologies that may be adopted to identify project risks. It remains a process that relies heavily on the experience and insight knowledge of project personnel. Risks have typically been identified through several methods including brainstorming, workshops, checklists, questionnaires and interviews, literature review, and knowledge-based systems (De Zoysa and Russell 2003). Upon identifying risk items to which a project might be exposed, most construction organizations store them in the form of a risk register. Such registers have been identified as “extremely effective tools” by Patterson and Neailey (2002). However, no formal structure has been developed to systematically identify risks to which a particular project might be exposed. Typically, risk management in construction tends to depend mainly on individual key players (Tah and Carr 2000). These individuals adopt different terminology and techniques for describing and managing risks, which could potentially cause inconsistencies and ambiguities. A common language for describing risk is necessary to facilitate a consistent approach to assessment and quantification of its impact.
This paper presents a model, designed to automate the risk identification process and provide a systematic approach to reduce ambiguities. The proposed model accounts for several practical factors when identifying risks to which a project might be exposed, including project location, domain and size. The impact of project delivery system on potential risk items is also considered. The sources from which risk items were obtained are stored to enable subsequent assessment of their reliability. A prototype software, based on the proposed model is developed. It operates in Microsoft Windows® environment, providing a user friendly interface utilizing menus, dialog boxes and a toolbar. It provides various levels of access, ensuring security and integrity of its central database. It provides a vehicle for construction companies to continuously enhance and fine-tune their risk registers to store corporate knowledge, and efficiently draw upon it for potential business opportunities.

2. SCOPE

The proposed model automates the generation of risk items to which a project might be exposed, while embracing flexibility and practicality. It was developed in collaboration with a major Canadian contractor to automate the risk identification process, and as a the first phase towards the development of a risk management program. It is designed to aid practitioners in identifying various risks and opportunities to which a project might be exposed. It automatically generates a list of all risk items and opportunities to which a project is exposed, enabling users to select some or all of them, as per the unique requirements of each project. In addition to risk items, the proposed model stores: 1) the username of individuals who define/edit these risk items on a regular basis; and 2) sources from which these risks were obtained (personal experience/literature review). It is designed to be employed in the pre-bidding stage, building on the knowledge base and user’s experience.

An issue that caused some debate between researchers is whether the term “risk” should be confined to define threats, or whether it should be broad to encompass both threats and opportunities. A recent study (Raftery et al. 2001) determined that contractors pay more attention to threats than opportunities, even if the attached monetary values were identical. Recently, the trend has been to regard risks as both opportunities and threats, (see the Project Management Body of Knowledge (PMBoK 2000)). In this paper, it was decided that the term “risk” be used to define uncertain events with both positive and negative impacts on the project. This is because:

1. Opportunities and threats are not qualitatively different in nature, since both involve uncertainty and have the potential to impact project progress;
2. Adopting this nomenclature would aid management in both minimizing the impact of threats and maximizing the impact of opportunities; and
3. This approach would aid management in the adoption of an unbiased approach to risk management (Raftery et al. 2001).

When generating the list of potential risk items for a project, it was recognized that the adopted project delivery system has a significant impact on the risks to which a project might be exposed. Engineering/procurement/construction (EPC) and build-operate-transfer (BOT) delivery systems pose different risks that can impact the project being analyzed. Additionally, various types of contracts (e.g. lump-sum, cost-plus) allocate risks differently between contracting parties. The proposed model accounts for project delivery systems and adopted contract type. The following sections provide an overview of the proposed model.

3. RISK CLASSIFICATION

A coherent risk classification scheme has been identified as a crucial step in risk identification (Al-Bahar and Crandall 1990; De Zoysa and Russell 2003). A comprehensive review of risk classification schemes was conducted to establish the current state-of-the-art in the field and identify and categorize the various risk items to which a class of projects may be subjected. Classification schemes reported in literature, along with that developed by the industry partner were reviewed. Most classification schemes reported in literature divide risks based on either: 1) their source (e.g. Odeyinka 2001; CII 1989); or 2) ability to control them (e.g. Tah and Carr 2001). Another classification scheme was proposed by Tah and Carr (2001) based on their nature throughout project life cycle. From this viewpoint, risks are divided into static and dynamic. Static risks maintain their nature throughout project life or until they seize to pose a threat (or opportunity). That is to say, the probability of occurrence of the risk and its impact on project progress remain unchanged. On the other hand, the likelihood of
the occurrence of dynamic risks and their impact vary during the life cycle of the project. The events causing this class of risks should be constantly monitored, the likelihood of their occurring reassessed and their impact re-evaluated. Figure 1 depicts the proposed risk classification scheme, where risks are divided into two broad categories: generic and domain-specific (or sector-specific). Generic risks are those which are inherent in all projects, irrespective of their nature or the type of work involved. These are divided into five sub-categories based on their sources. These are: commercial, technical, location, client and own risks. Own risks include: 1) those which an organization poses to itself, such as availability of technical know-how and right staff within the organization to carry out a project successfully; and 2) competence of selected partners. Domain-specific risks, on the other hand, are dependent on the project type, and would only be relevant for a specific domain (e.g. transportation, power plants). In the current study, sixteen domains are defined, reflecting the sixteen domains which the industry partner is involved in.

The proposed classification scheme accounts for the adopted project delivery method (EPC vs. BOT). This enables the identification of risks that are inherent under differing project delivery systems (EPC vs. BOT projects). In that regard, risks are classified into three main groups (Figure 1, detail “A”): 1) BOT; 2) EPC; and 3) both risks. The definition of the third category acknowledges the presence of certain risk factors that are applicable irrespective of the project delivery method and accounts for the fact that a BOT project may include EPC-related risks. This accounts for the nature of BOT projects, which impose additional risks over and above those inherent under traditional project delivery systems. The prolonged planning horizon, increased number of project participants and markedly increased project variables increase a project’s vulnerability to external risks (Kumaraswamy and Morris 2002).

4. COMPUTER IMPLEMENTATION

The proposed model is implemented in a prototype software that operates in Microsoft Windows® environment. It is coded in Visual C++ Version 6, utilizing Microsoft Foundation Classes (MFC). It provides three levels of access: 1) administrator; 2) management; and 3) project team. Access privileges for each group are listed in Table 1. As the table shows, only administrators have access to all projects, while managers only have access to projects with which they are involved. Microsoft Access® is employed as the database management system (DBMS), using Open DataBase Connectivity (ODBC), which enables real-time updating of the database. The database enables management to query risk items based on the access level of the person who input them, enabling fast queries on various risk items and evaluating their value to the company. If approved by management, the risk item is no longer highlighted, otherwise it is deleted. This process is designed to encourage participation and help capture the company’s experience and builds on its reservoir of knowledge and expertise, while ensuring the integrity of the database.

The proposed model provides a simple, friendly graphical user interface, as shown in Figure 2. The left portion of the screen contains a tree view, similar to that of Windows Explorer®, listing a variety of data including defined projects and risks to which they are exposed, stored risk items and sources from which they were defined. Upon double clicking on a risk item defined for a project, the user can edit its probability of occurrence and/or potential impact. The right portion of the screen provides a more detailed description of the project at hand, its domain, cost, project delivery method, location and risk items to which it is exposed, along with their probability of occurrence and potential impact. The user can edit these risk items to suit the unique conditions of each project through: 1) adding risk items; 2)
deleting risk items; or 3) revising a risk item’s probability of occurrence and/or potential impact. This increases the model’s flexibility, enabling it to continuously adjust to account for dynamic risks (Tah and Carr 2001).

**Figure 2. Main software screen**

The dialog window shown in Figure 3 is designed to define new risk items. It captures all required data to categorize and store defined risk items in the database. For generic risk items, a sub-category (commercial/technological/client/own/ location), while for domain-specific risks, a domain needs to be specified. The list of domains is also user-defined, enabling the software to be tailored to the domains of expertise of the user, and enabling its modification to accommodate emerging domains. The project delivery method that gives rise to the risk item also needs to be defined, along with the minimum project cost with which it is associated. The same dialog window is employed to input opportunities (risks with positive impact on project cost/schedule), as the user can select whether the risk item is a liability or a potential gain. It is worth noting that a description of the risk item is also required as input in order to resolve any ambiguities that might arise regarding its nature and what it covers. Periodic review of defined risk items and their definitions would avoid duplicity and aid in developing a company-wide terminology regarding risk.

**Figure 3. Dialog window to define new risk item**

The software employs a two-stage approach to identify risks to which construction projects (within the sixteen pre-defined domains) might be exposed. The first stage is project definition, which is carried out employing the dialog window shown in Figure 4. All variables required to determine risk items to which a project might exposed are input using that dialog window. Upon defining the project, and based on its domain, estimated cost and delivery method, a broad group of risk items is retrieved from the database. The data included in the dialog window shown in Figure 4 is all the input that is required of the user to generate its checklist of risk items.

**Figure 4. Stage one: project definition**

The second stage employs the dialog window shown in Figure 5, and entails selecting risk items relevant to the project at hand from a list of risk items that might potentially impact a project. As the figure demonstrates, the dialog window
contains two lists of the generic and domain/sector specific risk factors. The project shown in Figure 4 is an environmental project constructed using the BOT delivery system. As the figure shows, the software retrieves relevant risk items from the database and lists them alphabetically for the user to select some or all of the listed items. In the case shown in the figure, risks applicable to both: 1) BOT-related risks; and 2) risks applicable to both EPC and BOT delivery systems are considered relevant. This query is carried out for both generic and domain-specific risks (in this case, environmental) to develop the electronic checklist shown in Figure 5. Once this list is developed, it could be subject to further review for further additions and/or deletion, as the project team deems fit. To reduce ambiguities, a description of a risk item can be reviewed by double-clicking on its name.

Figure 5. Stage two: selecting risk items

Upon completion of this stage, a project-specific checklist of risk items is developed as shown in Figure 2. These items can later be revised to account for the dynamic nature of the construction industry. The effort required to generate a risk checklist for a construction project has been reduced to two simple point-and-click dialog windows.

5. CONCLUSIONS

This paper presented a model, designed to automate risk identification for construction projects. The project was part of a collaborative research program with a major Canadian contractor. A robust risk classification scheme is proposed to aid in the risk management process. The proposed model employs a two-step approach to generate project-specific checklist of risk items that require management’s attention. It is implemented in a computer software that operates in Microsoft Windows® environment. It provides a user-friendly interface, minimizing the time and effort required to identify risks to which a project might be exposed. It aids in achieving conformity in risk terminology within the company, aiding construction companies to develop a well-defined business culture towards risk management.

6. REFERENCES


Table 1. Levels of access enabled in proposed model

<table>
<thead>
<tr>
<th>Privileges</th>
<th>Administrator</th>
<th>Management</th>
<th>Project Team</th>
</tr>
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<tr>
<td>Access to projects</td>
<td>All</td>
<td>Restricted</td>
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<td>Define new risk items</td>
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<td>Yes</td>
<td>Yes*</td>
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<td>Define new project/deleting project</td>
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</table>

* Pending management approval
The use of a simulation model as a game for teaching project control in construction

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ABSTRACT: Construction management education, like most education and indeed, most things, is changing rapidly. There is a move towards student centred learning which is intended to allow students to gain knowledge at their own pace and develop transferable skills during the course of their education. In Construction Project control is an essential task of management of projects and good planning and control have long been recognised as having beneficial effects on the success of a project. However the efficacy of control techniques that are widely taught in management courses is almost impossible to prove. It is also very difficult on a theoretical basis to help students to understand the effects of their decisions and thereby enable them to learn the mixture of science and art, which is project control. The use of management games for teaching in construction has the advantage of enabling participants to be put into complex, realistic project situations without incurring the financial and time penalties, which would accrue if real projects were used. This paper describes a simulation model of an earthmoving project, which is used as a management game, to provide players with experience in the management and control of construction projects. The model contains many of the aspects of a real project including planning, decision-making, uncertainty, environmental effects, finance and a realistic physical model of the project and resource operation. The paper draws conclusions both on its effectiveness for control and on its use for teaching and learning.

KEYWORDS: Construction; Management Games; Project Control, Simulation

1. INTRODUCTION

Project planning and control are two of the essential tasks of project management. Good planning and control have long been recognised as having beneficial effects on the success of a project. Poor planning and control, on the other hand, have also been recognised as major contributors to the poor performance of projects. Not surprisingly therefore, most, if not all, undergraduate courses in project management, contain elements of planning and control. Most medium and large sized organisations invest large amounts of money, time and effort, training their professionals in planning and control. Whilst this training is more practical than the theoretical approach adopted in most undergraduate programmes, the techniques used are usually traditional. The effectiveness of the techniques taught in these courses is, at best, difficult to prove. Some work has been done to determine and illustrate the differences between different control mechanisms (see for example Al-Jibouri and Mawdesley, 1998) and several authors have developed new planning methods and criticised others (see for example Karim, 1999). However, such work is based on theories rather than practice and none of it takes into account all of the aspects of a project and the inherent complexity brought about by their interaction.
In addition to the difficulty of assessing the effectiveness of planning and control, assessing the effectiveness and efficiency of a method of teaching them is problematical. People learn through a variety of mechanisms and what is viewed as good by one person for one topic may be viewed as being less good by another person or by the same person on a different topic. Some will like to learn by studying theories while others will like to learn by example and practice.

This paper describes an attempt to provide a mechanism for people to learn about planning and control of a project by experiencing them. It uses a simulation of a construction project which participants can plan and control with some degree of reality but without the inordinate cost implied by learning on a real project. The simulation model is described and experience with it is discussed. Student feedback on certain aspects is provided.

![Project Simulation for Planning and Control](image)

**Figure 1. General arrangement of the site**

2. THE SIMULATION/ GAME

The idea of using a computer simulation or management game to help students learn about complex issues is not new. Gilgeois and D’Cruz (1996) describe games stretching back over many years. The use of management games for teaching and learning about project planning and control is also not new and was described by Scott and Cullingford in 1973. Further, Au and Parti (1969) described the use of a game using a project with a significant amount of earthmoving as a basis. Not all games have to be complex and computer based and Tommelein et al (1999) describe one which can be run either manually or on a computer to illustrate the interaction of parties on a project. More recently, the Internet has featured with games as part of the learning environment (Sawhney et al 2001).

Despite all these developments, games are still little used in the real world, perhaps because of their inability to capture the attention of people brought up with computer games as a major form of entertainment. Whilst not competing with the leisure games, this game combines the experience of players and traditional teachers and engineers to provide a user interface and style of play that is both interesting and informative.
The detailed objectives of the game are:

- To provide a ‘realistic’ model of a construction project which will react in physical and financial terms to the decisions made and actions taken by the player
- To provide reports as might be expected on a real project
- To include uncertainty but to control it in such a manner as not to hide the effects of control actions
- To be suitable for use by both undergraduates and practicing engineers.

2.1 The user interface

The game is written in Pascal and was developed in the Borland Delphi IDE. The interface was designed to make use of the computer power and to develop and maintain the players’ motivation and to present the players with reports which might be expected on a real project.

2.2 The project

The game is based on a project to construct a rock-fill dam with a clay core. The finished dam is 30m high and 300m wide at the top. Figure 1 shows a general arrangement of the site. It indicates some of the features to be considered by the player including the design and maintenance of temporary haul roads; the environmental impact of the work (including working close to a Site of Special Scientific Interest); and the effect of the work on neighbours. This is in addition to the normal planning and control considerations present on an isolated site.

2.3 The player’s tasks

The player takes the part of the contractor’s project manager and is responsible for the planning, resource selection and use, the control and the reporting to the company management. Planning is required for both the physical and financial aspects of the project. It must be carried out and the project plan input to the computer before work can start on the actual construction. The plan can be amended at any time but the system remembers all plans and reports against the agreed one.

Resources are required to excavate, transport and place the rock and clay and to maintain the haul roads. A typical screen for the choice of plant is shown in Figure 2. Basic information on the
equipment is provided on this screen but it is usually insufficient to make effective decisions. To aid the player and to increase the verisimilitude of the game various resources are provided. These include:

- Links to web sites of equipment companies such as Komatsu and Caterpillar
- Links to web sites of contracting organisations
- Links to notes and PowerPoint presentations on equipment selection and use
- Links to notes on the operation and use of teams of equipment.

Management resources are also required and have to be selected by the player. For example, the number of engineers to supervise the rock excavation, transport and placing must be considered together with the amount of money to be spent on training them in the quality, safety and environmental matters.

2.4 Reports

The player receives reports from the game in many formats as would happen on a real project. There are some aspects which would be picked up from meetings and mail. These are reported as text and are illustrated in Figure 3. It can be seen that these refer to a large range of aspects including work quality, environmental impact, training issues and problems with progress. This type of information would be obtained from many sources in reality and would depend on the staff and reporting mechanisms on the project. In the game, the amount of this material also depends to some extent on the staff and its training.

The more formal control information can also be provided by the system although its availability depends directly on the staff employed. If few staff are employed, few reports will be produced or can be viewed. The information is available in numerical form or it be produced as several forms of graph. Figure 4 shows a graph of performance variance during construction.

All the most common control charts are available from the system and players can choose which they want to use to help them make decisions.

3. EXPERIENCE WITH THE GAME

The game has been run as part of a generally lecture based course. Participants worked in small groups (2,3 or 4). Groups were both necessary, because of the large number in the class, and beneficial because they encouraged discussion and peer learning.

Before starting work on the project, each group was required to produce a programme of work, a financial plan and a proposed control method. These had to be presented to the main company board.

In every case, it was observed that the students were optimistic in their view of the project. The plans showed that the plant would work at optimum output, there would be no effect of team working, the plant fleets would always be balanced, no uncertain events would happen and control would hardly be necessary. Students were
prepared to defend their view of the project even when questioned. They had analysed the data provided and were convinced that they had the ‘correct’ solution.

The agreed plan was input to the system before work on the dam commenced. Each group was then able to ‘run the game’ (or work on their own project) independently but had to report to the group board as agreed at the briefing.

The game monitored progress against this plan and attempted to make suggestions as to the need to re-plan. If re-planning were done, the system monitored against both the original plan and the most up-to-date plan available.

Participants very quickly realised the optimism of their original plan and took some form of control action. In almost all cases, this involved trying to build the plan at the planned rate and ignoring all other aspects (finance, quality, safety and the environment).

At the end of the project, each group was asked to report to the management board of the company to explain its performance. This ensured that the students thought carefully about their decisions.

Student feedback was also sought through a questionnaire. The main points reported by the students include:

- The difference between theory and practice
- The importance of obtaining realistic rather than optimistic data
- The importance of control
- The need for planning and control even when faced with an uncertain world

4. EFFECTIVENESS OF CONTROL AND LEARNING

The use of a game to teach management can be justified on many levels but it is important to attempt to assess its effectiveness. To this end, the game produces a summary measure of the performance of the player throughout the game and the results of this are presented below.

4.1 The summary measure

In addition to the normal project control parameters, the system produces a summary measure which is a linear arithmetic combination of the following factors:

- Current balance – planned balance
- Current clay height – planned clay height
- Current rock height – planned rock height

The lower the value of the summary measure the better the player is performing relative to the plan. A score of 50 would be considered excellent and a score of 500 would be poor.

4.2 Participant performance

Eleven groups of 3 players were monitored during their playing of the game and the values of the summary measure, which they achieved, was recorded. The average result of the groups over time is shown in figure 5.

![Figure 5. Average performance of groups](image)

Several points can be made from these results. Firstly, the game is made particularly easy at the start as the weather is set to have little uncertainty and consequently has a minimal effect on the progress of the work. This is reflected in the general reduction in the summary score over the first few weeks of the project. Players can use this initial period to understand the effects of control actions.

As the game progresses, the uncertainties inherent in the game increase. This is caused by many factors such as the equipment affecting the haul roads, the effects of the initial safety, quality and environmental training, and the weather changing as a different period of year is reached. At this stage, all players experienced a considerable amount of difficulty controlling their project to plan as can be seen by the marked increase in summary measure.
However, players generally learned how to control the situation and the summary measure decreased in most cases. By the end of the project, the work could be considered to be in control although all were some considerable distance from their planned position. (The increase in measure towards the end of the project is caused by some groups going over their allowed duration and incurring liquidated damages costs) Although this graph indicates a general improvement, the performance of the individual groups is not so clear. This is shown in figure 6.

![Figure 6. Performance of groups relative to their own worst measure value](image)

In this figure, the performance of individual groups relative to their own maximum summary figure is shown. Once again, the smaller the value, the better the performance. From this it can be seen that some groups performed much better than others. The worst groups were still achieving summary measure values near their maximum 75% of the way through the project indicating that they were having great difficulty controlling their performance. This is also apparent in the shallow gradient of the line. The best groups, by contrast, were able to improve their performance consistently throughout the last half of the project.

5. CONCLUSIONS

The paper has described a game which has been produced to help with the teaching and learning of project planning and control. It has also described some of the experience gained from its operation. Students commented on how the game gave them and insight into the reality of projects, which theories did not allow.

The attempts at measuring the performance of the players provide some evidence of the learning effects of the game although more experiments are necessary to determine whether or not these are really achieved.

The game is based on a single dam-construction civil engineering project. Another game is under development based on the building industry and allowing players to experience the benefits and drawbacks of employing subcontractors rather than permanent employees.

6. REFERENCES


A methodology to select construction equipment

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ABSTRACT: Planning in the construction industry, as is well known plays an important part in the successful outcome of a project. How a task has to be dealt with and with which tools is part of the engineers work load and it is in their responsibility to assure that this planned work is carried out on time and within its constraints. Construction equipment is among these tools that have to be carefully chosen.

The traditional way to choose equipment was by its performance, in terms of maximum productivity at the lowest cost. Present pressures from governments and other institutional agencies as well as general conscience are forcing the construction industry to further adopt safety and environmental aspects in their normal way of functioning, and so every activity or process that a company carries out has to be rethought in order to achieve this integration of other parameters.

The aim of this paper is to present the results of a research project for creating a methodology to select construction equipment, combining the use of several well known methods for each of the aspects involved in the selection and using the multi-criteria analysis to reach at the final choice or recommendation.

KEYWORDS: Construction equipment, Performance, Labour risks, Minimal impact, Multi-criteria analysis.

1. INTRODUCTION

Planning in the construction industry, as is well known plays an important part in the successful outcome of a project. How a task is to be dealt with and with which tools, be they technical or management oriented, is part of the engineer’s work load and it is his responsibility to assure that this planned work is carried out on time and within its constraints. Construction equipment is among these tools that have to be carefully chosen.

2. METHODOLOGY

Starting from the notion that construction equipment should be selected by its performance on site, the first stage in this research project was to choose the right method for measuring this performance. For each of the different types of equipment a specific method had to be selected.

The construction equipment was divided in 6 groups:

- Earth movement equipment
- Material handling equipment
- Elevation and rising equipment
- Concrete equipment
- Auxiliary equipment
- Portable machines

And for each type the methodology used to analyze the different criteria was based in:

- Measuring the performance
- Measuring the minimal risk
- Measuring the minimal impact or environmental aspect
- Calculating by the multi-criteria analysis method which of the options is the most suitable
### Table 1. Steps of the methodology

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>USED METHOD TO ANALYSE IT</th>
</tr>
</thead>
</table>
| Optimum performance                           | Minimal hourly cost  
Maximum hourly productivity                                                                                                                            |
| Minimal risk                                  | The minimal risk criteria, will be the result from the sum of all the present risks. The valuation of these risks was made through the method proposed by the INSHT. (Instituto Nacional de Seguridad e Higiene del Trabajo). |
| Minimal impact or environmental aspect        | The minimal impact or environmental aspect, will be the result from the sum of all the present impacts. The valuation of these impacts was made through the method of identification and evaluation of environmental impact and aspects based on the Environmental Management Systems contained in the ISO 14001 standard. |

### 3. OPTIMUM PERFORMANCE

#### 3.1 Measuring the productivity

For each of the different types of equipment the productivity was measured by several ways, for example, in earth moving equipment, established methods were used, as the Caterpillar method for their equipment, and for other types of equipment productivity was measured on site under normal conditions of use.

#### 3.2 Hourly costs

The hourly cost for each of the equipments, as in the productivity was obtained either by established methods or by doing a market research on the price for renting that equipment for a established period of time and dividing it by the actual time of usage.

#### 3.3 Factor the influence the performance of construction equipment

There are several factors that can affect or influence the performance of construction equipment and that can be gathered in the following groups:

1. **Routine delays:**
   All those factors that are derived from the inevitable equipment use, no machine can function at maximum power continuously. Maintenance falls into these kind of delays.

2. **Restrictions to optimal mechanic operation:**
   These originate a reduction effect on production, due exclusively to limitations to its optimal operation. Slopes, angles, heights, cutting depths, etc, are all restrictions of this kind.

#### 3. Site conditions:

Once on site different kinds of factors can affect the performance of given equipment, some are:

a) **Physical conditions:** topography and geology of the site, geotechnical characteristics of the ground or rocks, etc.

b) **Climate:** temperature, rain, snow, etc.

c) **Localization of the site:** how near is the site from urban centers or industrial sites for provisioning.

r) **Adaptation conditions:** degree of adaptation of the work team can sometimes hinder the performance of the equipment.

#### 4. Direction and Supervision:

Organization of the workflow, planning and other management decisions can pose obstacles for maximum performance.

All of these factors were quantified in order to obtain a real production of the equipment.
### Table 2. Risk valuation

<table>
<thead>
<tr>
<th>Severity</th>
<th>LIGHT</th>
<th>HAZARDOUS</th>
<th>EXTREMELY HAZARDOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Low probability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Trivial risk 1</td>
<td>Tolerable risk 2</td>
<td>Moderate risk 6</td>
</tr>
<tr>
<td>Medium probability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Tolerable risk 2</td>
<td>Moderate risk 4 ≈ 6</td>
<td>Important risk 12</td>
</tr>
<tr>
<td>High probability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Moderate risk 6</td>
<td>Important risk 12</td>
<td>Intolerable risk 36</td>
</tr>
</tbody>
</table>

### 4. MINIMAL RISK CRITERIA

The minimal risk criteria is obtained as follows:

1) Identify and evaluate all the present risks of the equipment, according to the general process of risk evaluation established by the INSHT. (Instituto Nacional de Seguridad e Higiene)
2) Valuation of the found risks, by a numeric scale.
3) Finally all the values for each equipment are summed which gives the value of the minimal risk criteria

#### 4.1 General risk evaluation method proposed by the INSHT.

To evaluate the present risks in the use of construction equipment the General risk evaluation method proposed by the INSHT was used and it is composed of several steps:

A. –Classification of all the work activities that require the use of construction equipment.
B. –Risk analysis
   B.1. –Danger identification
   B.2. –Risk estimation
      B.2.1. –Severity
      B.2.2. –Probability
C. –Risk valuation. This valuation is made with the help of Table 2.
D. –Prepare a risk control plan
E. –Revision of the plan

### 5. Minimal impact or environmental aspect

The minimal impact or environmental impact of construction equipment is obtained as follows:

1) Identification and evaluation of all impacts present on a given equipment applying a descriptive method based on the criteria of an environmental management system as the ISO 14001 standard.
2) Valuation of the encountered impacts according to their criticality.
3) The sum of all the values of specific equipment, this result gives the “minimal impact or environmental aspect”.

#### 5.1 Descriptive method used for identification and evaluation of environmental impacts.

The identification is made by a questionnaire that guides the evaluation team; this tool has to be adapted to the necessities of the activity to be carried out. The questionnaire considers the following factors:

- Controlled and uncontrolled emissions
- Controlled and uncontrolled leaks
- Residue generation
- Utilisation and contamination of the ground
- Water, fuel, energy consumption
- Visual impact
- Noise and vibrations
Table 3. Example of a proposed format

| Equipment: |
| Activity/Task: |
| Filled by: | Date: |
| Yes No | Questions | Aspects (to be filled in case of an affirmative answer) |
| 1. Energy use? | Types and quantities |
| 2. Use of natural resources? | Types and quantities |
| 3. Use of chemical products? | Types and quantities |
| 4. Use of other hazardous materials? | Types and quantities |
| 5. Leaks or spills? | Types and quantities |
| 6. Atmospheric emissions? | Types and quantities |

Table 4. - Impact valuation

<table>
<thead>
<tr>
<th>Graveness</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low prob.</td>
<td>1</td>
<td>Trivial Criticalness</td>
<td>Tolerable Criticalness</td>
</tr>
<tr>
<td>Mediu m prob.</td>
<td>2</td>
<td>Criticalness tolerable 2</td>
<td>Moderate Criticalness 4 ≈ 6</td>
</tr>
<tr>
<td>High prob.</td>
<td>6</td>
<td>Moderate Criticalness 6</td>
<td>Important Criticalness 12</td>
</tr>
</tbody>
</table>

Table 3 is an example of a proposed format for the questionnaire and the factors involved in the analysis of the environmental impacts.

In this identification a problem arises, that is, up to what point or how exhaustive does the person analyzing the environmental impacts has to be, given that every equipment has to some degree implicit impacts. For this research project, logic was predominant over the extensive search for impacts, so a reasonable amount of impacts were identified and evaluated. In any case as the method is used over a period of time, preventive measures adopted can give way to more strict and extensive list of environmental impacts.

5.2 Multi-criteria analysis

This technique evaluates the different alternatives through punctuation according to the criteria involved in the analysis of the objectives set, and gives specific weight to each of the criteria according to its relative importance. The format of the method was adopted from Dell'Isola (1997), based on a combination between two matrixes, one of the punctuation of the criteria and the other the analysis of the alternatives. The basic steps are as follows:

- **Step 1**: Selection of the criteria, which are placed on the left side of the punctuation matrix followed by a letter and ordered in
alphabetical order. The criteria have to have some degree of independence between them.

- **Step 2**: Assignment of punctuation to each of the criteria according to its relative importance. This punctuation has to be as objective as possible so for this research project the following table was used to assign the relative weight.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Higher degree of preference over the other criteria</td>
</tr>
<tr>
<td>3</td>
<td>Medium degree of preference over the other criteria</td>
</tr>
<tr>
<td>2</td>
<td>Lesser degree of preference over the other criteria</td>
</tr>
<tr>
<td>1</td>
<td>No degree of preference between criteria</td>
</tr>
</tbody>
</table>

As an example two valuations have been made in Figure 1, the C/2, stands for a lesser degree of preference of the C criteria when compared with the A criteria. The B/1 punctuation means that between criteria B and D there is no degree of preference.

- **Step 3**: Once the comparisons have been completed, the raw score has to be established for each of the criteria. This score is the result of the sum of the taxation of the previous step. This enables the establishment of the relative weight for each of the criteria in a scale form 1 to 10. The highest raw score gets 10 points, and to the 0 value gets the minimal weight, 1. The rest of the values are assigned in a linear manner according to the established values. Figure 2 is an example of this raw score assignment.

- **Step 4**: Having obtained the relative weights for each of the criteria in a scale form 1 to 10, the analysis of each of the alternatives is the next step. To have a common scale for all of the criteria established the values obtained in each of the criteria have to be normalized by a linear equation:

\[
Y = \frac{y_1 - y_0}{x_1 - x_0} (x - x_0) + y_0
\]

- **Step 5**: Finally each valuation is reflected in the matrix by multiplying the relative weight of each criterion by its specific value.

- **Step 6**: To end the analysis the final step is to obtain the global score for each alternative by adding the results of each individual criterion and placing this result on the right column of the matrix. The optimal solution or alternative is the one with the lowest score, when there are similar scores various alternatives can be selected. Figure 3 is an example of the final matrix.
6. CONCLUSIONS

The described method for the selection of construction equipment has proven its results in practical cases and has been of great help to the persons responsible for this kind of decisions. Although some time and effort has to be invested in the development of all the criteria for each of the equipment involved in a construction project the decisions can be supported on a scientific method, thus being able to take less risks when purchasing equipment.

7. REFERENCES

Estimating the Dependability’s in Constructions

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ABSTRACT: In this paper an approach for the throughput evaluation of the construction manufacturing systems is presented. The throughput is evaluated with a heap-based algorithm for the Petri nets model of the construction systems. The Petri nets model is a stochastic one, and the firing rate of the transitions are calculated with Markov chains models of the component subsystems of the manufacturing system. The advantages of this approach are:

- constructing a system level Markov chain (a complex task) is not required;
- it permits to evaluate transient and steady-state performance of alternative designs based on different availability of the system’s components;
- the heap based throughput algorithm is simpler than the traditional timed event graph version;
- it introduces the availability of the human factor in the theoretical model of a construction system.

KEYWORDS: Stochastic Petri nets, Markov chains, system availability, heaps of pieces.

1. INTRODUCTION

Construction systems include a set of manual operations, and a set of automatic operations. A major consideration in designing a construction system is its performance. When a machine or other component of the system fails, the system reconfiguration is often less than perfect. The notion of imperfection is called imperfect coverage, and it is defined as probability c that the system successfully reconfigures, when components break down [1]. We assume that when the repair of the failed component is completed it is not as performance as a new one. In this paper a dependability model for evaluating the performance of a construction system is presented. The meaning of dependability is:

- System availability;
- Dependence of the performance of construction system on the performance of its subsystems and components;
- Dependence of designing the stochastic Petri nets model, Markov chains, and special automata over the (max, +) semiring, which compute the height of heaps of pieces (respectively the throughput of the system).

Stochastic Petri nets (SPN) were developed by associating transitions/places with exponentially distributed random time delays [2], [3]. These methods are based on results obtained from the underlying Markov chain for such systems. Extended SPN were developed to allow generally distributed transitions delays in the case of non-concurrent transitions. For concurrent transitions, exponential distribution is required for exact solutions. The underlying models of these PN are semi-Markov processes. Heaps of pieces: In [4], Viennot observed that trace monoids are isomorphic to heap monoids, that is monoids in which the generators are pieces (solid rectangular shaped blocks), and where the concatenation consists of piling up one heap above another. This yields a very intuitive graphical representation of trace monoids. For us, a useful interpretation of a heap model consists of viewing pieces as tasks and slots as resources, where by slots we use the following model [5]. A piece is a solid block, occupying some of the slots, with staircase-shaped upper and lower contours. With an ordered sequence of pieces, we associate a heap by piling up the pieces, starting from a horizontal ground. A piece is only subject to vertical translations and occupies the lowest possible position, provided it is above the ground and the pieces previously piled up.

2. THE STOCHASTIC PETRI NETS MODEL OF A CONSTRUCTION SYSTEM

A SPN is a six-tuple (P,T,I,O,m,F), where:
P={p_1, p_2, ..., p_n}, n>0, is a finite set of places;
T={t_1, t_2, ..., t_s}, s>0, is a finite set of transitions with P ∪ T ≠ 0, P ∩ T = ∅; I: P×T→N, is an input function where N={0,1,2,...}; O: P×T→N, is an
output function; $m: P \rightarrow N$, is a marking whose $i$-th component is the number of tokens in the $i$-th place. An initial marking is denoted by $m_0$. $F: T \rightarrow \mathbb{R}$, is a vector whose component is a firing time delay with an extended distribution function. By extended distribution functions, we mean that exponential distribution functions are allowed for concurrent transitions. Two transitions are said to be concurrent at marking $m$ if and only if firing either does not disable the other. The firing rule for an SPN provides that when two or more transitions are enabled, the transitions whose associated time delay is statistically the minimum fires. According to the transition-firing rule in PN, when a transition $t_k$ has only one input place $p_i$, and $p_i$ is marked with at least one token, $t_k$ is enabled. The enabled transition can fire. The firing of $t_k$ removes one token from the $p_i$ and then deposits one token into each output place $p_j$. Let $P(i,k)$ be a probability that transition $t_k$ can fire. The process from the enabling to the firing of $t_k$ requires a time delay, $\tau_k$. This delay $\tau_k$ of a transition can be either a constant or an extended random variable in SPN. $P(i,k)$ and $M(s)$ depend on $\tau_k$ as well as the current marking and the time delays of other enabled transitions at that marking. $M(s)$ denote the moment generating function, and is defined as follows:

$$M(s) = \int_{-\infty}^{+\infty} e^{st} \cdot f(t) \cdot dt$$

(1)

Where $s$ is an extended parameter, and $f(t)$ is a probability density function of random variable $t$.

Of course, we have: $M(0) = \int_{-\infty}^{+\infty} f(t) \cdot dt = 1$. A transfer function of a stochastic Petri net [4] is defined as the product $P(i,k) \cdot M(s)$, and is:

$$W_k(s) = P(i,k) \cdot M(s)$$

(2)

Transition $t_k$ characterized by $P(i,k)$ and $\tau_k$ is expressed by a transition characterized by $W_k(s)$. Three fundamental structures can be reduced into a single transition. The reduction rules can be used to simplify some classes of PN. With these reduction rules we transform PN into finite state machines (in a finite state machine each transition has only one input and output place, and there is one token in such a net). Fig.1, a,b,c depict these reduction rules.

$$\Leftrightarrow$$

![Figure 1. Equivalent transfer functions for three basic structures of PN](image)

The moment generating functions for the state machine PN which models the construction systems represent the availability of the cells (subsystems) which form the PN, and are computed with Markov chains models of the subsystems as shown in the following capitol.
3. AVAILABILITY OF A CONSTRUCTION SYSTEM

We defined above the notion of imperfect coverage, c. We will show the impact of imperfect coverage on the performance of the construction system. We will demonstrate that system availability will be seriously diminished even if this imperfect coverage constitutes a small percentage of the multiple possible flaws of the system. This aspect is generally ignored or overlooked in the current managerial practice. The availability of a system is one probability that should be operational when needed. This availability can be calculated as the sum of all probabilities of operational states of the system. To calculate the availability of a system we need to determine the acceptable levels of functioning degree of the system’s states. The availability of the system is considered acceptable when the production capacity of the system can be assured. Considering the big dimensions of a construction system, the multiple interactions among its elements as well as between the system and the environment, in order to simplify the graphs and reduce the amount of calculus we will divide the system into two subsystems. These two subsystems are the following: equipment subsystem (the machine factor) and the man subsystem (the human factor in construction activities). In its turn the equipment system is divided into cells. The Markov chain is built for each cell i, where i=1,2,...,n (n represents the number of cells into which the equipment and human systems are divided) to determine the probability for at least k_i equipment to be operational at a certain moment t, where k_i represents the minimum of well functioning equipment which preserves the cell i operational (for the equipment subsystem), respectively to determine the maximum allowed number of wrong actions of the workers (human subsystem).

The availability of the system is given by the probability of the operator doing his duty between k_i operational equipment in cell i and k_{i+1} operational equipment in cell i+1, at moment t.

Supposing the levels of the subsystems are statistically independent, the availability of the system is:

$$A(t) = \prod_{i=1}^{n} \left( A_{im}(t) \cdot A_{ih}(t) \right) \quad (3)$$

Where: $A(t)$ = the availability of the construction system (man-machine system); $A_{im}(t)$ = the availability of the i cell in the equipment system at moment t; $A_{ih}(t)$ = the availability of the cell i in the human subsystem at moment t.

3.1. The equipment system

The expectation of an i cell of the equipment system which includes N_i equipment of the type n_i is to ensure the functioning of at least k_i of the equipment for the system to be operational. To determine the availability of the system including imperfect coverage and faulty repairs for each cell there has been introduced a state of malfunctioning caused either by imperfect coverage or by technical failure. To explain the effect of imperfect coverage of the system we will consider that operation O_1 can be made with one of the equipment M_1, respectively M_2.

![Figure 2. Subsystem consisting of one operator and two machines](image-url)
probability that at least \( k_i \) equipment should function in cell \( i \) at moment \( t \).

We can calculate this probability according to the following formula:

\[
A_i(t) = \sum_{k=k_i}^{N_i} P_k(t), \quad i=1,2,\ldots,n
\]  

(4)

Where: \( A_i(t) \) = the availability of cell \( i \) at moment \( t \); \( P_k(t) \) = probability that, at moment \( t \), cell \( i \) should contain \( k_i \) operational equipment; \( N_i \) = number of \( M_i \) equipment in cell \( i \); \( k_i \) = minimum number of operational equipment in cell \( i \).

3.2. The human factor subsystem

The expectation from the human factor subsystem is that it should ensure the exploitation of equipment with maximum efficiency and safety. To determine the availability of the operator to be capable of performing his duty at moment \( t \), we build this Markov chain (Fig.4) which models the behavior of the cell \( i \) of the human subsystem. In Fig.4, we have:

\( \lambda_h \) = the rate of wrong actions of the operator; \( \mu_h \) = the rate of correct actions of the operator in case of break down; \( \gamma_h \) = the covering factor of problems caused by wrong actions or by unexpected events occurred in the system; \( r_h \) = the factor of correcting wrong actions of operators.

In Fig.4 the human operator can be in one of the following states of performing his job: state \( N_i \) = normal working state in which actions are performed by all \( N_i \) operators of cell \( i \); state \( k_i \) = working state where actions are performed by \( k_i \) operators (\( k_i< N_i \)); state \( F(k_i+u) \) = working state allowing incorrect actions which can cause technological malfunctioning with no serious consequences on the safety of traffic, where \( u = 0,\ldots,N_i-k_i \); state \( Fk \) = state of working incapacity due to wrong actions with serious consequences on traffic safety.

The availability of the human factor due to perform his duties under normal circumstances is:

\[
A_{th}(t) = \sum_{x=1}^{m} P_x(t), \quad i=1,2,\ldots,n
\]  

(5)

Where: \( P_x(t) \) = the probability that the operator is in working state \( x \) at moment \( t \), in cell \( i \); \( m \) = total number of working states allowed in the system; \( j \) = minimum allowed number of working states.

Attributing supplementary working states to the human factor considerably increases the complexity of the calculus, and furthermore, although the entire system continues to work, certain technological norms are disregarded which leads to low throughput in the construction system.
4. PERFORMANCE EVALUATION OF A CONSTRUCTION SYSTEM

A construction system is specified by the following properties: 1) A finite set \( R \) of resources (machines and operators); 2) A finite set \( T \) of elementary tasks; 3) For each task \( d \in T \), a duration \( \tau(d) \) and a single machine cell \( i, R(d) \in R \) on which \( d \) is to be executed; 4) A finite set \( B \in T \) of production sequences or jobs. Each job \( J=a_1a_2…a_k \in B \) is composed of a finite number of tasks \( a_1, a_2, …, a_k \) to be executed in this order. A job is produced each time the sequence \( J \) is completed. This model is equivalent to the one given in [5], where the following algorithm for the performance evaluation of safe jobs (the assumption of safe job is equivalent to state machine Petri net as defined above). The algorithm has the following steps: Input: a job-shop, a pattern of transitions \( v \); 1) Build the heap model, and its associated matrices \([5]\) \( M(d) \), \( d \in T \); 2) Compute the product of matrices \( M(v) \); 3) Compute the (max, +) value of \( M(v) \), \( \rho(M(v)) \), using Karp algorithm, where \( \rho(M(v)) \) is the (max, +)value of \( M(v) \). In [5] it is shown that this algorithm has the complexity \( O(|v|(|B|+|R|)+(B|+|R|)^2) \). We notice that this algorithm, in comparison with other algorithms for performance evaluation in discrete event systems, do not need a new time event graph to be build for each new schedule. This is of great advantage for us, because we give to the random variables different values in order to build different scenarios for the construction system optima schedule.

5. CONCLUSIONS

Our work develop heuristics and performance bounds for scheduling, based on heap and automata representation. The performance of a construction system is evaluated, in many scenarios, with a SPN in which a transition can be associated with either a constant or random firing time delay with an exponential distribution, computed with a Markov model which incorporates the notion of imperfect coverage, and imperfect repair factors. An advantage of the Markov model is that the construction of large Markov chains is not required. Another advantage is that it allows performing sensitivity analysis of an entire construction system, as well as of its components. The novelty of this approach is that it incorporates the availability of the human factor. We can generalize the proposed approach, when instead of decomposing the global system in two major subsystems, one can decompose the system into three, four, … subsystems, according to the specific application. We may notice that a large number of subsystems determine an embarrassing growth of the calculus complexity. In this paper we assumed that the failure and repair times were exponential random variables. In real construction systems, the time distributions are arbitrary, which can be handled semi-Markov processes. A state transition may not occur at any time, and the failure/repair time can follow an arbitrary distribution. When a failure/repair event occur, the Markov process representation applies, and the probability of burning a transition to a new state depends only on the current value of state.

6. REFERENCES


Understanding the Links between Project Success and Technology Usage via Work Function Characteristics

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ABSTRACT: More than 200 capital facility projects from across the U.S. have been assessed on the issue of technology usage at the work function level and overall project cost and schedule success. Work functions (WFs) that may leverage project cost and schedule performance were identified. The analyses suggested that degrees of technology used in executing these project performance-leveraging work functions may have a significant impact on project cost or schedule performance.

This paper explores the links between technology utilization and project success in further detail. The techniques used for analyzing the associations include cost performance sensitivity, schedule performance sensitivity, and analysis of Work Function Characteristics (WFCs). Cost and schedule performance sensitivity analyses of project performance-leveraging work functions are employed as a way to gain greater understanding of the connection between technology usage and project performance. In addition, WFCs were investigated as an additional basis for gaining deeper insights into how technology usage may impact project success. The analysis results indicate that information & data intensive, human resource involved, and management-related WFCs can positively influence project cost and schedule success.

KEYWORDS: Project Success; Technology Utilization; Work Function; Work Function Characteristics.

1. INTRODUCTION

An industry-wide survey was used to collect project data from more than 200 capital facility projects on the issue of technology usage at the work function (WF) level and overall project success. Work functions that may leverage project cost and schedule performance were identified [O'Connor and Yang 2002]. The analyses suggested that degrees of technology used in executing these work functions may have a significant impact on project cost or schedule performance. These cost and schedule performance-leveraging work functions were further analyzed using cost performance sensitivity, schedule performance sensitivity, and Work Function Characteristics (WFCs) analysis to explain the links between technology utilization and project success.

Work Function Characteristics are differentiae that characterize the work functions. Six categories of Work Function Characteristics were developed to classify work functions by their attributes and as a way to study differences between work functions relative to technology usage: 1) nature of work function procedures, 2) time/space/cost factors, 3) information and data aspects, 4) WF management, 5) nature of WF product, and 6) nature of human resource [O'Connor and Won 2002]. Table 1 presents a list of the 31 Work Function Characteristics by category (not all WFCs can be applied to each work function).

Work Function Characteristics were used to better understand project performance-leveraging work functions through analysis of their attributes. WFC analysis reveals characteristics common to the cost and schedule performance-leveraging work functions. To gain more insight into how the use of technology affects project success, the following research hypothesis was developed:

Hypothesis: Work Function Characteristics can, in part, explain the links between project success and technology utilization.
Table 1. List of WFCs by Category

<table>
<thead>
<tr>
<th>(H) Human Resource</th>
<th>(P) Work Function Product</th>
<th>(T) Time/Space/Cost</th>
<th>(I) Information &amp; Data</th>
<th>(M) Management</th>
<th>(D) Work Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1: Many individuals are involved to perform WF</td>
<td>P1: Performance of many subsequent WFs relies heavily on this WF</td>
<td>T1: WF is a critical path activity in most cases</td>
<td>I1: WF involves uncertainty information</td>
<td>M1: A specialty organization is involved in most cases</td>
<td>D1: WF involves iterations and revisions</td>
</tr>
<tr>
<td>H2: WF involves many individuals with different skills and specialties</td>
<td>P2: WF product is physically large and bulky</td>
<td>T2: WF activity requires spatial coordination</td>
<td>I2: Historical data from previous projects are required for execution</td>
<td>M2: Many different types of organizations are involved</td>
<td>D2: WF is error prone</td>
</tr>
<tr>
<td>H3: User's, worker's or operator's experience is critical to performance</td>
<td>P3: Errors are difficult to fix or require a large amount of resources to fix</td>
<td>T3: WF involves relatively high uncertainty in the following item (cost, schedule, quality, and safety)</td>
<td>I3: WF relies on industry technical standards</td>
<td>M3: Primary performance driver of the WF is one of the followings (quality, safety, cost, and schedule)</td>
<td>D3: WF procedures are driven by regulations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T4: WF management operates in close proximity to workers</td>
<td>I4: WF data are in many different formats</td>
<td>M4: Responsible individual must communicate frequently with others</td>
<td>D4: WF involves repetitive activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T5: WF involves environmental hazard</td>
<td>I5: Data accuracy is crucial to successful WF performance</td>
<td>M5: WF involves high probability of change</td>
<td>D5: Some WF resources are often idle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T6: WF is costly to execute</td>
<td>I6: Security of related data is very important</td>
<td></td>
<td>D6: WF procedures are very complex</td>
</tr>
</tbody>
</table>

This paper explores the links between technology utilization and project success in further detail. Cost and schedule performance sensitivity analyses of project performance-leveraging work functions are employed as a way to gain greater understanding of the connection between technology usage and project performance. In addition, WFCs were investigated as an additional basis for gaining deeper insights into how technology usage may impact project success.

2. COST PERFORMANCE SENSITIVITY

According to the analysis of technology usage at the work function level, a total of 19 work functions that may leverage project cost performance were identified [O'Connor and Yang 2002]. Table 2 presents these cost performance-leveraging WFs. It is reasonable to think that these work functions involve factors or characteristics that may affect the cost performance of a project. Cost performance sensitivity analysis of these work functions may provide some explanation of the connection between technology utilization and project cost success. Seven of the 19 cost performance-leveraging work functions are thought to be cost-sensitive. These cost-sensitive work functions involve significant financial expenditure or are closely associated with cost control.

3. SCHEDULE PERFORMANCE SENSITIVITY

Table 3 lists the 18 work functions that may leverage project schedule performance [O'Connor and Yang 2002]. These schedule performance-leveraging work functions as a matter of logic involve factors or characteristics that likely affect the schedule performance of a project. Schedule performance sensitivity analysis of these work functions may be helpful in explaining the connection between technology utilization and project schedule success. Nine of the 18 schedule performance-leveraging work functions are thought to be schedule-sensitive. These schedule-sensitive work functions involve significant time duration or are closely associated with schedule control.
Table 2. List of Cost Performance-Leveraging WFs

<table>
<thead>
<tr>
<th>ID</th>
<th>Work Function</th>
<th>Thought to Be Cost-Sensitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01</td>
<td>Conduct market analysis or need analysis for a new facility</td>
<td>X</td>
</tr>
<tr>
<td>1.03</td>
<td>Model user's process</td>
<td>X</td>
</tr>
<tr>
<td>2.05</td>
<td>Prepare floor plans</td>
<td></td>
</tr>
<tr>
<td>2.08</td>
<td>Design electrical systems</td>
<td></td>
</tr>
<tr>
<td>2.09</td>
<td>Design HVAC systems</td>
<td></td>
</tr>
<tr>
<td>2.10</td>
<td>Document the assumptions used in developing the budget, and pass to next phase</td>
<td>X</td>
</tr>
<tr>
<td>2.14</td>
<td>Track design progress</td>
<td></td>
</tr>
<tr>
<td>3.03</td>
<td>Link quantity survey data to the cost estimating process</td>
<td>X</td>
</tr>
<tr>
<td>4.06</td>
<td>Track the inventory of materials on site</td>
<td>X</td>
</tr>
<tr>
<td>4.10</td>
<td>Constructors provide feedback about the effects of design changes on cost and schedule</td>
<td>X</td>
</tr>
<tr>
<td>4.13</td>
<td>Update as-built drawings</td>
<td></td>
</tr>
<tr>
<td>4.15</td>
<td>Owner payment to contractor</td>
<td></td>
</tr>
<tr>
<td>5.07</td>
<td>Fabricate roof trusses</td>
<td></td>
</tr>
<tr>
<td>6.02</td>
<td>Train facility operators</td>
<td></td>
</tr>
<tr>
<td>6.03</td>
<td>Use as-built information in operator training</td>
<td></td>
</tr>
<tr>
<td>6.06</td>
<td>Monitor equipment operations</td>
<td></td>
</tr>
<tr>
<td>6.08</td>
<td>Update as-built drawings in response to facility modifications</td>
<td>X</td>
</tr>
<tr>
<td>6.09</td>
<td>Monitor/track/control facility energy usage</td>
<td></td>
</tr>
<tr>
<td>6.10</td>
<td>Monitor environment impact from operations</td>
<td></td>
</tr>
</tbody>
</table>

4. WFC ANALYSIS AND DATA COLLECTION

In order to identify characteristics associated with the cost/schedule performance-leveraging work functions, a total of 10 project performance-leveraging work functions were selected for analysis. The selected work functions for Work Function Characteristic analysis are listed in Table 4. The data collection effort involved characterization of these selected work functions. For the selected work functions, data were collected from 11 industry professionals from the Owner, A/E, or GC groups. Respondents to the survey included presidents, vice presidents, project managers, project engineers, and project planners. These professionals averaged 22 years of experience, with a minimum of 12 years and a maximum of 30 years.

Table 3. List of Schedule Performance-Leveraging WFs

<table>
<thead>
<tr>
<th>ID</th>
<th>Work Function</th>
<th>Thought to Be Schedule-Sensitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01</td>
<td>Conduct market analysis or need analysis for a new facility</td>
<td>X</td>
</tr>
<tr>
<td>1.02</td>
<td>Develop, evaluate, and refine the project’s scope of work</td>
<td>X</td>
</tr>
<tr>
<td>1.03</td>
<td>Model user's process</td>
<td>X</td>
</tr>
<tr>
<td>1.05</td>
<td>Develop a milestone schedule from the scope of work</td>
<td>X</td>
</tr>
<tr>
<td>2.11</td>
<td>Detect physical interferences</td>
<td>X</td>
</tr>
<tr>
<td>3.04</td>
<td>Link between supplier cost quotes and cost estimate</td>
<td>X</td>
</tr>
<tr>
<td>3.09</td>
<td>Acquire &amp; review shop drawings; send response</td>
<td>X</td>
</tr>
<tr>
<td>4.01</td>
<td>Develop detailed construction schedule</td>
<td>X</td>
</tr>
<tr>
<td>4.09</td>
<td>Communicate Requests for Information &amp; response</td>
<td>X</td>
</tr>
<tr>
<td>4.10</td>
<td>Constructors provide feedback about the effects of design changes on cost and schedule</td>
<td>X</td>
</tr>
<tr>
<td>4.14</td>
<td>Submit contractor's request for payment</td>
<td>X</td>
</tr>
<tr>
<td>5.02</td>
<td>Earthwork &amp; grading</td>
<td>X</td>
</tr>
<tr>
<td>5.06</td>
<td>Provide elevated work platform</td>
<td>X</td>
</tr>
<tr>
<td>5.09</td>
<td>Acquire &amp; record material lab test results</td>
<td>X</td>
</tr>
<tr>
<td>6.02</td>
<td>Train facility operators</td>
<td>X</td>
</tr>
<tr>
<td>6.03</td>
<td>Use as-built information in operator training</td>
<td>X</td>
</tr>
<tr>
<td>6.07</td>
<td>Request facility maintenance or modifications</td>
<td>X</td>
</tr>
<tr>
<td>6.08</td>
<td>Update as-built drawings in response to facility modifications</td>
<td>X</td>
</tr>
</tbody>
</table>

4.1 Characterizing Work Functions

For each subject work function, the survey asks participants to assess the extent to which individual WFCs apply to that work function. This survey offers respondents five optional responses: Strongly Agree, Agree, Neutral, Disagree, or Don’t Know. For any given WFC, the assessed degree to which a
WF relates to that WFC was established as the WFC Score. In order to perform quantitative analysis, responses were converted to WFC Scores as follows: Strongly Agree = 4, Agree = 3, Neutral = 2, and Disagree = 1. The WFC applicability index was computed and then translated to a 0-10 point score:

\[
\text{Mean WFC Applicability Index} = \left[ \frac{\text{Sum of WFC Scores associated with all project performance-leveraging WFs}}{\text{Total number of project performance-leveraging WFs}} - 1 \right] \times \frac{10}{3}
\]

A WFC Applicability Index score of zero indicates “not applicable.” A value of 6.67 or greater indicates “highly applicable.” Figure 1 illustrates the degree to which individual WFCs relate to the cost and schedule performance-leveraging WFs. The plot is divided into four quadrants. The points located at the upper right quadrant represent WFCs with high applicability for both cost and schedule leveraging WFs. If a data point is located in the lower left quadrant, it indicates that the WFC has little applicability to the leveraging WFs. Figure 2 displays the data set representing the WFCs that may explain leveraging. Each data point represents a Work Function Characteristic. The farther to the right a point is located, the more strongly the WFC relates to the schedule performance-leveraging WFs.

### 4.2 Identification of Common WFCs Trends

Mean WFC applicability index values of 6.67 or greater are associated with high applicability WFCs. Nine WFCs that may explain leveraging were identified in the WFC analysis. These WFCs show a strong association with the cost and/or schedule performance work functions. Table 5 presents the high applicability WFCs. Most of the WFCs that may explain leveraging fall in the following three WFC categories: 1) human resource, 2) information & data, and 3) management. This indicates that information/data-intensive, human resource involved, and management-related WFCs may greatly influence project cost and schedule success.

Work Function Characteristics that may explain cost performance-leveraging were identified in order to explore project cost success determinants. The analyses suggest that data/information-intensive and management-related Work Function Characteristics may greatly influence the cost performance of a project. Work functions that involve significant amount of data updating and repetitive activities deserve the execution with high technology approaches. In addition, degrees of technology used in executing the work functions that involve many different types of organizations and frequent communication between individuals likely affect the cost performance of a project. The priority for technology implementation is also associated with the work functions for which data accuracy and user’s experience are critical to performance.

Work Function Characteristics that may explain schedule performance-leveraging were identified to further explain the links between technology utilization and project schedule success. The analysis results indicate that data/information-intensive and human resource involved Work Function Characteristics may have potential influence on the schedule performance of a project. Technology usage for work functions associate with historical data and data security may help improve project schedule performance. Consideration should be also given to employ higher levels of technology usage for the work functions that
involve many individuals and personnel communication. In addition, the priority for technology implementation is associated with the work functions for which data accuracy and user’s experience are critical to performance.

5. CONCLUSIONS

The techniques used for analyzing the associations between technology usage and project success include cost performance sensitivity, schedule performance sensitivity, and analysis of Work Function Characteristics. Cost and schedule performance sensitivity analyses of project performance-leveraging work functions were used as a way to gain greater understanding of the connection between technology usage and project success. WFCs were also investigated as an additional basis for gaining deeper insights into how technology usage may impact the cost and schedule performance of a project. The results indicate that the project performance-leveraging work functions involve factors or characteristics that may affect project cost and schedule success. These analyses also suggest that data/information-intensive, human resource involved, and management-related Work Function Characteristics may greatly influence the cost or schedule performance of a project. Work functions that involve data accuracy and frequent communications between different individuals and organizations deserve the high technology approaches in order to achieve higher levels of project cost and schedule success. In addition, the priority for technology implementation is also associated with the work functions for which worker’s or operator’s experience is critical to performance.

6. REFERENCES


![Figure 1. Relationships between WFCs and Project Performance-Leveraging WFs](image-url)
**Figure 2. WFC Analysis for Project Performance-Leveraging WFs**

**Table 5. WFCs That May Explain Leveraging**

<table>
<thead>
<tr>
<th>Category</th>
<th>WFCs</th>
<th>Cost Leverage</th>
<th>Schedule Leverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Resource</td>
<td>H1: Many individuals are involved in the WF</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>H3: User’s, worker’s or operator’s experience is critical to</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information &amp; Data</td>
<td>I2: Historical data from previous projects are required for execution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I5: Data accuracy is crucial to successful WF performance</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I6: Security of related data is very important</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I7: WF involves significant amount of data updating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management</td>
<td>M2: Many different types of organizations are involved</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M4: Responsible individual must communicate frequently with others</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Work Procedure</td>
<td>D4: WF involves repetitive activity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Probabilistic model simulation in cement process fabrication at Casial Factory

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ABSTRACT: This paper will propose to investigate results obtained from automated measuring process control of temperature in cement fabrication with the simulation modeling by probability distribution functions and conducted at yield goodness of fit results. The simulation’s results enable the comparison with the data obtained by automated real-time project process data which are used in classical analyses of manufacturing process for economical and technical management decision.

KEYWORDS: Distribution, functions, modeling, probability, simulation,

1. INTRODUCTION

Experimental measurements of quantities such as pressure, length, temperature, force will always exhibit some variation if the measurements are repeated a number of times with precise instruments. The data obtained from repeated measurements represents an array of readings, not exact results. A trace-driven process control or simulation using this large data set can be developed, however, there are major drawbacks to such a course of action as the process control or simulation will reproduce solely what has already happened.

2. GENERAL CONSIDERATION ABOUT PROCESS

The Trading Company Casial Deva is concerned with the cement and building materials fabrication, as part of the construction materials industry. In 1998, Casial Company was privatized 51% of the company’s shares being taken over by the investors of the Lasselsberg Group, Austria and now it is a subsidiary of Heidelberger Zement, Germany.

The clinker represents 80.4% of the cement as a result of the flour (homogenous mixture of limestone, clay and pyrite) partially decarbonized in the burning installations (kiln furnace). During this phase, specific thermodynamic processes, at a temperature $T_K$ of 1450°C carry out the clinkerization process. The kiln furnace contains the following areas:

I. decarbonization area
II. solid phase reactions area
III. clinkerization area
IV. cooling area

The preheated flour, at a temperature $T_F = 780-800°C$, known as the material’s temperature, and partially decarbonized, passes into the kiln furnace during the I-II-III-IV sequence, receiving the heat from the heated gases at $T_G = 1000-1050°C$.

The gases go into the heat exchanger, being evacuated at the upper part at the cyclone. Secondary air (7-10%) is pumped into the cooling area (clinker cooler), with a controlled temperature $T_a$. Another input parameter is represented by the coating’s temperature $T_{ma} = 110-410°C$, as measure of the heat exchange between inside -outside of the kiln furnace. [Arad]

All these inputs are continuously controlled, aiming to provide a proper output, between the admitted limits, around the clinkerization value. The temperature in the clinkerization area is an output variable $y(t)$ needing to be regulated.
3. PROBABILITY DISTRIBUTION FUNCTION

The problem of collecting and analyzing data confronts all researchers trying to model real world activities. Fitting a statistical distribution to a collecting of sample observations usually approaches the required process inputs for a simulation model.

The Weibull distribution provides a more suitable approached to the statistical analysis of the available data. The Weibull distribution curves are not symmetric, and the distortion in the S-shaped curves is controlled by the Weibull slope parameter \( m \). This distribution function \( P(x) \) defined as

\[
P(x) = 1 - e^{-\left(\frac{x-x_0}{b}\right)^m}, x \leq x_0
\]  
(1)

Where \( x_0, b, \) and \( m \) are the three parameters that define this distribution function. However, to determine the Weibull parameters, \( x_0, b, \) and \( m \) requires additional conditioning of the data. [Dally]

4. MATHEMATICAL MODEL AND SIMULATION

The process of the flour burning is a continuous fabrication process with several random variables. In order to determine the process’s model the responses to the pulse or step signals are analyzed. These tasks do not involve only building of the physical model but include the collection and processing of data, numerical regulation, quality improvement of the regulation, optimization and hardware and software implementation. [Landau]

By using an experimental identification technique, it is possible to design a direct identification technology of the dynamic model based on a transfer function. The answer can be simulated on a first degree system according the statistical analysis of the process’s input and output data and the response of the continous process for an uniraty step input

The regulation and control of the output parameter, the clinkerization temperature, is essential in order to provide a linear and continuos functionaing of the process.

One of the most important aspects of the design and implementation of a regulator is to evaluate the obtained results. It is most important to determine, around a certain temperature, \( T_k \), a dynamic model linking the furnace’s temperature with the regulator's command.

The mathematical model, in time domain, describing the system's activity in dynamic regime, is the one generated by the first grade system I.

The existence of modern calculation systems, enabling high speed calculations as well as the electronic systems of data acquisition allowed the processing of the experimental data, improved the measurements’ precision and created the possibility of developing devices able to generate sampling signals according to a well established program.

The data obtained from monitoring of output parameter represent a sample of size 20 from an infinite population of all possible measurements that could have made.

By using the proper software TableCurve (TCWin), the temperature’s variation in the furnace, \( T_k \), is approximated with a polynomial function (see Figure 1)

\[
Y = a + b \ln x + c (\ln x)^2 + d (\ln x)^3
\]  
(2)

Where, \( y \) is temperature of kiln furnace, and \( x \) is the time.

The parameters characterizing the statistical distribution of the output vectors were also determined with this software.

Maximum information can be extracted from this sample by employing statistical methods can be readings on Table 1 and 2.

We obtained confidence interval for predictions, Stunent's t and error.

5. RESULTS

The TableCurve (TCWin) software was used to performe statistical analysis of the input data – as a result was obtained the equation (2) simulating the mathematical model of the process’s output parameter. Among the 44 processed equations, the equiation presenting the higher correlation coefficient \( r^2 = 0.965 \) was selected. (see Figure 1, Table 1).

The variation of the output parametere being comparable with the variation of the furnace’s
coating temperature during the heating process (Figure 2). Once the furnace reached the nominal functioning temperature, the furnace’s internal temperature variation, measured by using a pyrometer, showed a slightly variation around the clinkerization temperature. The temperature’ variation inside the furnace, during 8 hours, for nominal functioning, is shown in Figure 3. The output parameter varies according the slightly variation of the other assessed parameters of the process (temperature of seondar air $T_a$, temperatura of gases $T_G$, temperature of material $T_F$ during the three stages of clinkerization).

Table 3 gives a concise overview of the data inputs $T_a$, $T_G$, $T_F$ (during the three stages of clinkerization) and output temperature $T_K$ for each hour of the monitoring period.

6. CONCLUSIONS

Statistical methods are extremely important in engineering, since they provide a means for representing large amounts of data in a concise form that is easily interpreted and understood. Usually, the data are represented with a statistical distribution function.

The most significant advantage resulting from the use of a probability distribution function in engineering applications is the ability to predict the occurrence of an event based on a relatively small sample. The effects of sampling error are accounted for by placing confidence limits on the predictions and establishing the associated confidence levels.

It is most important to maintain kiln temperature $T_K$ constant and out of any disruptions, due to economical reasons—meaning the reduction of energy consumption.

The versatility of the numerical computers enables the implementation of the automatic estimation algorithms for the parameters of the discrete model describing the flour burning and cement production.

7. REFERENCES


[Table Curve] Table Curve™ Jandel Scientific AISN Software.
### Table 1. Statistical parameters of data

<table>
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<tr>
<th>Parm</th>
<th>Value</th>
<th>Std Error</th>
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**Area Xmin-Xmax** | **Area Precision**
20989.470554 | 4.895643e-05

**Function min** | **X-Value** | **Function max** | **X-Value**
-39518.11572 | 1.674427e-10 | 1298.7877758 | 10.80006e-05

**1st Deriv min** | **X-Value** | **1st Deriv max** | **X-Value**
-6.45247362 | 18.000000e00 | 7.984762e+08 | 1.800006e-05

**2nd Deriv min** | **X-Value** | **2nd Deriv max** | **X-Value**
-2.05863e13 | 3.600009e05 | -0.353166056 | 17.997864766

**r2 Coef Det** | **DF Adj r2** | **Fit Std Err**
0.9651324516 | 0.9558344387 | 73.106757952

**Source** | **Sum of Squares** | **DF** | **Mean Square** | **F-value**
Regr | 2367012.4 | 3 | 789004.14 | 147.626
Error | 85513.569 | 16 | 5344.5981 | Total | 2452526 | 19

### Table 2. Results of confidence intervals for predictions

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### Table 3. Data inputs and output temperature process in eight hours.

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Figure 1. Kiln Pyrometer temperature variation and statistical data processed by TCWin
Construction Conceptual Cost Estimates Using Evolutionary Fuzzy Neural Inference Model

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National Taiwan University of Science and Technology, Department of Construction Engineering, Taipei, Taiwan 10672, R.O.C.
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ABSTRACT:
The conceptual estimate plays an essential role in project feasibility study. In practice, it is performed based on estimators’ experiences. However, due to the inaccuracy of cost estimate, budgeting and cost control are planned inefficiently. In order to increase the estimate accuracy, this study employed the Evolutionary Fuzzy Neural Inference Model (EFNIM) to develop an Evolutionary Construction Conceptual Cost Estimate Model (ECCCEM).
The ECCCEM is designed for owners and planners to perform order of magnitude estimates and conceptual estimates. The impact factors of cost estimate are identified through literature review and interview with experts. Applying the EFNIM, the evolational construction conceptual cost estimate model is established. Furthermore, for automating the developed model, this study integrates the Evolutionary Fuzzy Neural Inference System (EFNIS) with the developed model to construct a web-based cost estimate system. This system can assist managers to estimate the project costs accurately for different purposes.

KEYWORDS: Conceptual Estimate, Fuzzy Theory (FT), Genetic Algorithm (GA), Neural Network (NN), Order of Magnitude Estimate.

1. INTRODUCTION
Cost estimate of engineering is the foundation of all project-related engineering. It is based on planning, designing, bidding, and even construction. For owners and planning authorities, the data of cost estimated can be the evaluation base of feasibility of project, design with content and cost control during engineering execution. Based on the analysis of curve of management control of engineering, design of prototype and initial phase of design play an influential role during project.
The estimate of cost is based on owner’s need and geographical condition, and is, therefore, taken as a foundation for feasibility evaluation and design plan. In practice, at the stage of engineering initial plan and design, there are two ways to estimate cost, one is Rough Estimate and the other is Sketchy Estimate Method. The former uses Experimental Judgment, which requires experienced experts. With their experiences, engineering cost can be calculated subjectively. Whereas, even though the experts are experienced, the different standards in assessing may be hard to judge the precision of cost estimate. Further, a common way used in sketchy estimate is Factor Estimate. It uses past cases and chooses some engineering items with obvious cost percentage as base, then adjust engineering cost based on the ground of standard items and scales of other items [1]. Is it possible to present features of project and obtain a reasonable cost if calculation is resulted from key engineering items? These are still much more to be discussed. With the problems of Rough and Sketchy Estimates, an incompletion of data at initial stage, there is still a huge tolerance between estimate cost and actual one. It is estimated that the tolerance of Rough Estimate is ±25%, while Sketchy Estimate ±15% [2]. Hence, because of this tremendous tolerance, it is obvious that budget cannot be arranged and taken as a way to control cost for project based on the data from cost estimate.
The current way to estimate price is differentiated from stage. Based on engineering and construction cost, a rough estimate at conceptual planning stage is basic research of existing area and customer’s initial demand. Initial stage is to last conceptual planning stage, put it into practice, process initial design, and calculate a rough cost based on the
result of design. Therefore, it is hard to distinguish engineering stage between Rough Estimate and Sketchy Estimate. However, it is still a continuous operation. It is essential to consider the continuity of price estimate and estimate price based on Rough and Sketchy Estimates so as to build up a model for price estimate of information integration at varied stages. Moreover, time is rather short compared with schedule of initial design and planning with the stage of engineering execution. Thus, in order that cost can be estimated along with price estimate, a development of system for engineering cost will help establish a mechanism of rapid price estimate. To sum up, this research will develop an integrated estimation system, which consists of Rough and Sketchy Estimates, thereby the operation of engineering cost can satisfy needs, cost and time three dimensions [6].

2. RESEARCH OBJECTIVE

The objectives of this research are stated as below:
(1)Discussion of problems resulted from the method of engineering cost estimate
This research is to use the most commonly used Rough and Sketchy Estimate, analyzing their problems and developing a basis of price estimate model for Rough and Sketchy Estimate.

(2) Establishing a cost estimate model of construction engineering with information integration.

As the current way to estimate engineering cost is too simple. In order that Rough and Sketchy Estimate can fit the continuity of project development and effectively integrate it, this research will take Evolutionary Fuzzy Neural Inference Model (EFNIM) as core of price estimate model for Rough and Sketchy Estimate.

2.1 Architecture of EFNIM

EFNIM is configured under the structure of Fuzzy Theory, Neural Network and Genetic Algorithms. Its configuration is as Fig. 1. With these combined, advantages can be integrated while defects can be made up. In this model, Fuzzy Theory (FT) deals with inaccuracy and similar theories, while Neural Network (NN) is used for a maximum of learning curve; furthermore, Genetic Algorithms (GA) optimizes the whole model. The purpose to build this model is on the base of Intelligence Theory model. Therefore, the development of model is based on the theoretical process of simulated human brain combined with fuzzy theory. FT and NN are a compensated technology, the combination of which can effectively gain the features of human brain, thereby offering the development of IA an effective approach. In Fig.1 the Fuzzy Inference Engine and Fuzzy Rule in the traditional FT are replaced by NN, and the use of which is to overcome the attainment of Fuzzy Rule, decision of integrated algorithms so as to help system equip with learning ability. It is acknowledged that the combination of FT and NN is – The origin of nerve with fuzzy input and output. It is also a neural network with fuzzy input and output. To make the study easier, we call the origin of nerves with Fuzzy input and output as FNN.

Compared with traditional FT, though FNN can simulate the features and process of human inference, there are still some difficulties in terms of proper topology and selection of parameters. Besides, it may increase the difficulty and time based on the appropriateness of the selection of MFs (Membership Functions). Hence, GA could be an effective way to help resolve the defects of FNN.
As a result, EFNIM will use GA to simultaneously search for the most suitable mode of subsidiary function, and the best topology and coefficient of FNN.

3.2 Features and Limitations of EFNIM

EFNIM is inherited from the features and limitations of FT, NN and GA. It includes [3]:

(1) Features of EFNIM
a. It has an uncertainty, unclearness, and ability of partial unknown questions during the resolving process.

b. It has an ability of self-adjustment and learning in different environments.

c. It has ability to solve highly complicated problems.

d. It has fault tolerance.

e. It can find out the reflective relationship in input variable factors and output variable factors.

f. It can find out highly similar inference.

g. It can accumulate knowledge and experience.

(2) Limitation of EFNIM
a. It need training materials.

b. Training material should be correct and equally spread.

c. Solution should be a similar number.

4. ESTABLISHMENT OF COST ESTIMATE FOR CONSTRUCTION ENGINEERING

The model of cost estimate in this research can be divided into Rough Estimate and Sketchy Estimate. Rough Estimate means that during engineering planning, before designing, customers would develop a cost estimate model based on engineering objective, geographical information and initial idea. Sketchy Estimate means after initial design, customers could get an estimate of engineering total cost based on the assessment of engineering cost, and sum up each engineering cost.

4.1 Evaluation of Current Cost Estimate

There are 3 features in Rough and Sketchy Estimates:

(1) Experience-Oriented
Rough and Sketchy Estimates are different from Detailed estimate. Detailed estimate is used after engineering drawing and specification are completed, whereas Rough and Sketchy estimate are used merely based on a simple idea or an initial design. Thus, when information is insufficient, all that calculating personnel can do is to use their experience to assess the cost. With lots of experience notwithstanding, their estimate of cost may still have high tolerance based on their subjective judgment and different experience level.

(2) Method Too Simple
The current methods of cost estimates are related to analyze the relation between factors and cost, complete engineering projects and cost referring to some exemplary engineering items and predict cost via linear approaches. For instance, Factor estimate is based on engineering items with obvious cost scale, by which adjusts the basic items and relationship for scales of other items so as to procure cost estimate. However, the composition of engineering cost is complex, and is it possible that cost estimate can represent features of case based on obvious cost scale? Is the relationship between factor and cost a linear relationship? Thus, with a simple estimate approach, it is hard to get a precious cost estimate.

(3) Historical Cases as Basis
Historical cases can be regarded as basis during cost estimate. Thus, the success of cost estimate relies on the collection of historical cases, analysis and confirmation of engineering items needed for estimate.

4.2 Feasibility Analysis of EFNIM

This chapter will refer to the evaluation for the features or estimate methodology based on the infrastructure and features of EFNIM.

(1) Experience-oriented
EFNIM can use neural network to learn from cases and obtain the membership functions.
Therefore, it can help sort out calculating personnel with insufficient experience and varied subjective judging criteria, which resulted into a tolerance of cost estimate.

(2) Method Too Simple
EFNIM takes FNN as its inference engine, and uses GA to process FNN network by the best search in the entire area. It can effectively describe the relationship between the reasons for affecting cost estimate and engineering cost. It can simultaneously represent the impact on the cost estimate resulted from the relationship among factors.

(3) Historical Cases as Basis
Cost estimate model developed through EFNIM can reflect features of different cases onto the network architecture searched through the course of learning from abundant and represent-able historical cases. When facing different case, it can stand for its features and assess a reasonable cost.

4.3 Cost Estimate Model of Construction Engineering

4.3.1 Establishment of Model Architecture
The cost estimate models in this study are Rough Estimate and Sketchy Estimate as Fig.2. The rough estimate model drafted in the figure is based on engineering land price from related parameters. Sketchy estimates in the initial design stage are Engineering of hypothesis, engineering of foundation, engineering of structure, engineering of installation, electromechanical and equipment engineering, engineering of miscellany and indirect engineering, which can calculate the land price for each engineering and procure the sum of engineering land price according to the parameters for each model.

4.3.2 Influential Factors for Models

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<th>Model</th>
<th>Estimated Cost Model</th>
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<td>Sketchy Cost Estimate Model</td>
<td>Land Price of All Engineering</td>
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</table>

Through analysis of literature review, brainstorming, influence diagram, hierarchy of objective techniques and summary of influential factors for rough and sketchy cost estimates are:

4.4 Integration of Engineering Cost Cases

(1) Collection of Cases
The case resource is from an A-level plant in Taipei. This case mainly focused on the case of residential cluster for construction engineering. The period was from 1997 to 2001 and main location is in northern area of Taiwan. Land price for each Ping is between $40,000 to $100,000 NTD. Considering the uniformity and completion of data, there are altogether 28 cases about RC.

(2) Pre-treat for Cases Data
In response to the cost model request upon data type of cases, there are some pre-works for case data. Including input variables – quantitative factor and qualitative factor, qualitative and quantitative factors simultaneously, output variables– conversion of land price and normalization of land price. After historical cases are treated through input and output variables, they are able to be applied to training, the testing of cost estimate.

4.5 Design of Cost Estimate

(1) Rough Cost Estimate Model
It is based on the influential factor of Rough Estimate Model in Fig. 1. There are 10 input variables in rough estimate model while one output variable, which is land price of engineering.

(2) Sketchy Cost Estimate Model
Based on the influential factors of Sketchy Cost Estimate in Fig. 2, we assumed that there are 4 input variables of engineering cost estimate model and output variables are assumed as engineering land price; 7 input variables of fundamental engineering cost estimate model and output variables mean the land price of fundamental engineering. There are 8 inputs and 1 output (land price of structure engineering) of structure engineering. There are 9 inputs and 1 output (Land price of installation engineering) of installation engineering. There are 8 input variables of electromechanical equipments and output variables mean the land price of electromechanical equipment engineering. There are 5 inputs and 4 outputs of miscellany and indirect engineering and output mean the land price of engineering of miscellany and indirect engineering.

### 4.6 Training and Testing of Estimate Model

#### 4.6.1 Criteria of Model Evaluation

During initial stage of rough estimate, the tolerance is around ± 25%, and during sketchy estimate, the tolerance is around ± 15%. Based on the difference of estimate stage, during rough and sketchy stages, it may not be reasonable to demand for an accurate cost under the condition of limited time, budget and information. Thus, it is necessary to consider the need of accuracy during planning and initial designing stages and enhance the accuracy reasonably. In this study, we set the tolerance of land price of engineering during rough estimate stage to be within ± 15%, while within ±10% during conceptual planning stage, with the view of enhancing the accuracy of cost estimate reasonably.

#### 4.6.2 Training and Testing of Rough Cost Estimate Model

(1) Training and Testing of Rough Estimate Model

Based on the training cases 26 with EFNIM, proceeding the model training and executing the result as shown on Table 1. This result demonstrates that the cost tolerance through rough estimate model is within ± 15%, which indicates an accuracy to predict cost.

#### 4.6.3 Training and Testing of Sketchy Estimate Model

(1) Training and Testing of Sketchy Model

Based on the use of EFNIS, after the search and training for 6000 generations for engineering model from 7 groups. Used case 18 and 24 to demonstrate the engineering cost estimate model by items and the inferred output result is shown as Table 2. After calculation, the tolerance in case 18 and 24 are 7.812% and 2.058%, which is indeed within ±10%. Thus, based on this result, the establishment of Sketchy Cost Estimate Model in this study can definitely assess the accuracy of engineering land price by items.

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5. SKETCHY COST ESTIMATE SYSTEM IN CONSTRUCTION ENGINEERING

This study takes EFNIM as a core and EFNIS as a basis to build up sketchy cost estimate system in construction engineering and develop it based on
evaluating the demand of operational personnel. The functional module in this system contains: case management, case conversion, case calculation, price index management and module for user’s management, while in the mean time integrating the use of EFNIS.

6. CONCLUSIONS

In this thesis, we will summarize the above-mentioned process of study and achievement of study as follows:

(1) This study considers the phase of engineering life cycle and the stance of customers and consultants so as to design and integrate the rough cost estimate for prototype stage and sketchy cost estimate for initial design stage, thereby establishing an engineering cost estimate model with data linkage and cross-phase.

(2) This study combines the construction engineering cost estimate model in EFNIM, which effectively obtains experience from historical cases, summarizes regulation for cost estimate, and solves traditional cost estimate approach that only infers cost with some important engineering items. This study also improves the impact on subjective judgment by human.

(3) With the application of EFNIM, this study enhances the accuracy of price estimate effectively, and decreases the tolerance of rough cost estimate down to ±15%, while for sketchy cost estimate down to within ±10%.

(4) Based on the design of cost estimate model of construction engineering, this study takes EFNIS as its base and develops a cost estimate system for construction engineering. Considering the demand for price estimate process, the whole system is presented with internet pages, which is not limited by stand-alone system, thereby being able to offer many people of proceeding cost estimate process from far distance.

(5) Through the cost estimate model and system established by this study, the designing authority could calculate the engineering cost based on project contents proposed by customers. Customer could then assess the feasibility based on the proposed project contents and cost from related authority. A concrete project content and estimated cost could be established in time, as well as cost and requirement could fit the need.

7. REFERENCES


Daily Report Module for Construction Management Information System

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ABSTRACT: The profit of Construction Industry has been tremendously reduced for recent years in Taiwan. In order to survive in this difficult environment, “Management” becomes the key issue to achieve company’s target. We need a powerful tool that can help us to handle complicate process such as estimation, bidding, purchasing and site-management in the life-circle of a construction project. In this research, we develop a Daily Report Module for Construction Management Information System. In this module, we use Object Oriented concept to mimic project schema by dividing each item into building-floor-room hierarchy. In this system, all constructed items will be calculated and converged into money request data. This will heavily save the key-in time and prevent human mistakes from multiple-input. Through the help of this tool, we can effectively calculate the cash flow for a construction project and accurately control the amount that we can claim from owner and pay to subcontractors. It can also provide warning message to prevent overcharge or overpayment in construction operation. Through the help this system, we can integrate construction data and transport site information to the head quarter through world-wide-web immediately. This can help us to improve administrating capabilities, increase competition and make profit for construction companies.

KEYWORDS: Cash Flow, Construction Management, Daily Report, Object Oriented, and Site-Management

1. INTRODUCTION

The poor atmosphere of the construction business in recent years is putting a lot of local contractors into severe competition; improvement of management so as to uplift competitiveness is necessary for survival. While on the construction site side, there are indeed a lot of improvements that can be reached by refining the managing layers and cutting down costs; such as, via computer, a lot of manpower and man-hours can be saved. In welcoming the information-prompt age of networks, the construction industry must be able to follow the pace so as to compile a great amount of information into useful information in a short time, and so that competitiveness can be created. Therefore it is a necessary trend that the construction industry be informationized.

2. OBJECTIVE

In [1], we have constructed the Basic Database, Budget Module, Procurement Module, Price Calculation Module, and Settlement Management Module for CMIS-I. In this research, we use Object Oriented concept, Visual Modeling techniques with Delphi and ER/Studio environment to develop following modules for CMIS-II.

This study is mainly aimed for developing the Daily Report Module, Estimation And Pricing System, Design Modification Control System and Project Accounting System so as to compile the daily site management information into the current engineering value estimation, for the solution of problems of inaccurate input of site logs, repetitive works, high human errors in typing, over estimates or under estimates of engineering value etc. It is also for recording work items and quantities resulting from the design modification activated by the client or designer, as well as the finalizing quantity and amount of each project, so as to control the actual costs of projects.

3. FUNCTION REQUIREMENTS

The System Structure of CMIS consists the following items (Fig. 1):

1. Basic data structure for building up the system: database used is categorized into large, medium and small items.
2. To develop a Budget System program, to be able to generate project budget automatically.
3. To develop a Purchasing And Contracting System program, to be able to screen subcontractors and execute contracting.
4. To develop a Fund Auditing System program, to be able to place alarm for items exceeding the budget. (Above items have been completed in 2001.)
5. To develop a program of Daily Report System, to be able to record daily site work items, quantities and use of manpower and materials.
6. To develop an Estimation And Pricing System program, to be able to compile, from site daily log, quantities of the current finished items.
7. To develop a Design Modification Control System program, to be able to record items and quantities of every design change.
8. To develop a Project Accounting System program, to be able to control the finished items, costs and income, and expenditure for each project. (Items 5-8 are for the study of the present year.)

4. DATABASE STRUCTURE

4.1 Analysis of Database Structure

The structure of the database is the core of the whole system, should the structure be wrong, or the database be insufficient to meet the need, the whole data flow will cause error and result in outputting unexpected data, therefore it is extremely important to build up a suitable database structure.

Accompanying advances of information technology, the database system has developed from the conventional Relational Database to the Object-Oriented Database (OODB), which is now the mainstream of the development of database control systems [2]. This study uses ER/Studio tools to establish an ER Diagram, then, in the same mode, according to user need, makes the data flow chart and establishes the E-R (Entity-Relationship) Model; by defining the relationship between the databases, the substantial database is then built up and becomes the actual relationship database (Fig. 2).

![Figure 2. Database Structure Diagram](image)

After establishing ER/Model, the user can, with the tools provided by the program, translate the database structure into a Script File which can be retrieved by the general database systems (Fig. 3) so that Database Console loads the data list of the system, fields of the data list and the attributes of each field, as well as the relationship between the Primary Key and Foreign Key needed for the system database.

![Figure 3. Script File of the Database Generated by ER/Studio](image)

4.2 Construction Site Daily Log Flowchart

Site Daily Report, the record of daily work done and events occurred on the site, is the center of site managing. Information gathered through daily events, by proper compiling and analyzing, can deliver reports on the cost, progress and quality of the construction [3].
Site Daily Report, the record of daily site events, records a variety of occurrences around the site; this study categorizes the event information into engineering info, engineer info, manpower, equipment, material, quantity accomplished, location of work, test item, site event, and form filling etc.

The site daily report is not only a daily report sheet; it shall be used together with other forms such as climate record, engineer progress schedule, daily work-hour, equipment use record, steel bar use quantity, concrete pouring quantity, quantity of form, earthwork quantity etc., and most importantly, the engineering progress schedule and the work flowchart.

4.3 Process of Daily Report

This system constructs data structure of the daily report [4] as shown in Fig. 4. The system retrieves items from the basic database and translates them into “Project Work Items”; by combining with the daily activities logged in the report system and other related data -such as “manpower and material analysis database” and “contractor basics”—, information for project work items are compiled; in a building-floor-room format, the work items are entered according to their work site locations and are compiled and output as the site daily report. This log can be further compiled for set period of dates as the monthly log that provides information for pricing the estimation system.

![Figure 4. Daily Report Data Structure](image)

4.4 Process of Pricing Estimation

Pricing Estimation is closely related to procurement and tender process as well as the daily log. The study finds that items of the procurement programs in popular software on the market are base on work items; therefore the item in the pricing system derives directly from the work items compiled into the pricing list. Yet in reality, some projects are subdivided into several subcontracts and are separately carried out by different subcontractors in different scheduling. If this is done in terms of work items, the quantity in the log will not be able to combine with the item, and this can cause disputes when the subcontractor applies for payment. This is the reason that in this study we add the building-floor-room structure, so that subcontracting is done according to work item and work location, and the work accomplished can combine with the work item input and can be translated into pricing and estimation.

4.5 The Building-Floor-Room Structure

The study incorporated the Building-Floor-Room Structure [5], as described above and that is shown in Fig. 5, and combined with items in the project database. Items in the system contain work locations, in case of different subcontractors with different prices, this system is able to simulate the actual fulfillment by the said structure, which makes the information control more appropriate for work items. Formulas 1 to 3 are the relationships between building-floor-room and the work item; room works are compiled into floor work, and floors into building. Final summation is indicated as the accomplished quantity of the work item.

![Figure 5. Room-Floor-Room Structure Diagram](image)

\[
V_{\text{floor}} = \sum_{i=1}^{n_1} V_{\text{room}} \quad \ldots \quad \text{(Formula 1)}
\]

\[
V_{\text{building}} = \sum_{i=1}^{n_2} V_{\text{floor}} \quad \ldots \quad \text{(Formula 2)}
\]

\[
V_{\text{Sum of work item}} = \sum_{i=1}^{n_3} V_{\text{building}} \quad \ldots \quad \text{(Formula 3)}
\]

- \( V_{\text{room}} \): Quantity of work of each room, \( n_1 \): number of rooms on the floor.
- \( V_{\text{floor}} \): Quantity of work of each floor, \( n_2 \): number of floors in the building.
- \( V_{\text{building}} \): Quantity of work of each building, \( n_3 \): number of buildings in the project.
V sum of work item: Quantity of the work item in the project

5. SYSTEM STRUCTURE AND CONTENT OF WORK

Following completion of the Basic Database, Budget System, Procurement and Subcontracting System, and Cost Accounting System of the “Object Oriented Visualization-Simulated Structure of Constructional Information Compiling System (I)”, this study continues to develop the following subsystems:

A. Daily Report System
B. Estimation And Pricing System
C. Design Modification Control System
D. Project Accounting System

5.1 Daily Report System

Daily Report System consists of 3 modules—Project Info (Fig. 6), Work Item Info (Fig. 7), and Daily Report Input module (Fig. 8)—to record site events and work items accomplished; it also provides input of work location info. Besides, through company intranet via Client/Server structure, input can also be made by way of the browser input to upload daily log info to the main system at the headquarters.

System developed in the study provides 2 input methods: Direct Input (Intranet, shown as Fig. 8) and input through browser (Internet, as in Fig. 9).

5.2 Estimation and Pricing System

Estimation and Pricing System compiles info collected in the Daily Report, sums up to be used as the info and amount for pricing and estimation. By setting up the building-floor-room structure, the study handles work item quantity by summing up room work quantities in the floor and floor work quantities in the building, so as to get the compiled quantity of the work item.
After selecting “Project” and “range of pricing and estimation date”, the system compiles daily report info and translates into the Estimation and Pricing Database (as in Fig. 10, Screen Of Project Pricing And Estimation System, and Fig. 11, Project Pricing And Estimation System – add in and change the period of pricing and estimation); after entering the period of pricing and estimation, press the “OK” button and the system will translate the info into and for the use of the Estimation and Pricing System.

5.3 Project Modification Control System

There is always a need to change in every project. Whether due to functional requirements of the client or stipulations of the architectural regulations, because of the need of construction interface or purely due to design requirements, changes on plane setup, height, material, size and equipment etc. are needed. The Project Modification Control Module is meant to record and trace the item, time, quantity, and price and its payment term or every change in complete details, so that a better control of design change can be achieved.

This system added a Version field to the Project Info as one of the Primary Keys. When there is a need of design change being brought up by the client or architect in an Engineering Meeting, a new project version will be added (as in Fig. 12) to alter and record the changed item and quantity of each version.

5.4 Project Accounting System

Generally, by the end of the project, the contractor has difficulties in effectively handling the essentials of the project operation, which are the actually accomplished quantities, contract items and contract prices; only rough estimations can be worked out to approximate “tentative” profit or loss; in this environment that is more and more difficult to make a profit, it is truly needed to have complete control of the operation.

The system in this study can, coping with the Design Modification Control Module, control and trace the contracted quantity, subcontracted quantity and the finalized quantity etc., so that the operator can effectively control the relevant info and make necessary adjustments at all stages, as well as present the relative data at the end of the project to be used for project review and as references (as shown in Fig. 13, 14) to future project tenders, in the expectation of improving company managing ability and operating strength.
6. CONCLUSIONS AND SUGGESTIONS

The domestic construction atmosphere is generally low at the moment and contractors are facing enormous competitive pressure. Reinforcing competitive ability is the one and only method for a construction company to survive. The Construction Management Information System developed in this study has built up a Basic Database, Budget System, Procurement And Subcontracting System, Cost Accounting System, Daily Report System, Estimation and Pricing System, Design Modification Control System and Project Accounting System in the expectation of attaining the following effects:

A. To build up a basic data structure and present the system in the database categorized into large, medium and small items.
B. To develop a Budget System program, to be able to generate project budget automatically.
C. To develop a Purchasing And Contracting System program, to be able to screen subcontractors and execute contracting.
D. To develop a Fund Auditing System program, to be able to place an alarm on items exceeding the budget.
E. To develop a Daily Report System program, to be able to record daily site work items, quantities, and use of manpower and material.
F. To develop a program of Estimation And Pricing System, to be able to compile, from site daily log, quantities of the current finished items.
G. To develop a Design Modification and Control System program, to be able to record items and quantity of every design change.
H. To develop a Project Accounting System program, to be able to control the finished items, cost and income, and expenditure for each project.

6.2 Contributions

Through results of this study, contractors can execute the above mentioned compilation of construction information by using the “Construction Management Information System” and achieve the following effects:

A. By using computer software and log input interfaces, the system simplifies repetitive input tasks to simplify figure inputs.
B. Provides estimation and pricing period selections, which compiles from the Daily Report System and applies payment from the client; it can also serve the subcontractor in the same manner.
C. Builds up the “building-floor-room” structure into the database structure and solves the inconvenience of being unable to subcontract a single itemized work item.
D. Project Accounting System provides control of actually accomplished items in the project; this uplifts site management efficiency.
E. Reduces waste in use of equipment resources by way of resource integration, so as to lower costs and increase competitiveness.

6.3 Suggestions

Subsequent study of this research can extend to combine the “Progress Control Software” (such as MS-Project, P3 etc.) to achieve automatic compilation of the construction progress, update the Daily Report info into the Schedule Control Software so as to achieve real-time integrated construction management.
7. ACKNOWLEDGEMENT

I would like to take this opportunity to show my appreciation to National Science Council, Executive Yuan, for its support of the study. Project No.: NSC 91-2211-E-216-018.

8. REFERENCES


Study of Data Exchange for Use by Construction Information Systems

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ABSTRACT: Information technology (IT) that is achieving astounding progress has been applied to rationalize construction project management and is expanding the potential for the automation and use of robots in construction work. But the development of IT based systems has often resulted in cases where it is difficult for multiple systems to share electronic data because these systems were developed independently by different makers for use in different types of construction sites and to perform different types of work. In order to use information efficiently to gain the full benefits of such systems, it is vital to be able to transfer electronic data smoothly between construction information systems and between their sub-systems. This will also sharply reduce the cost of using construction information systems.

The authors have organized data exchange concepts and studied the data exchange standards needed to realize these concepts in order to propose a method for the sharing and exchange of data by a number of different construction information systems used to support the execution of civil engineering work. And taking a compaction control system as an example, they have analyzed the categorization and hierarchical structure of data to prepare a data model as the foundation for the construction of data exchange standards.

KEY WORDS: Construction Work, Construction Information System, Data Exchange, Data model, Data Exchange Standards

1. INTRODUCTION

Information technology (IT) that is achieving astounding progress has been applied to rationalize construction project management and is expanding the potential for the automation and use of robots in construction work. But the development of IT based systems has often resulted in cases where it is difficult for multiple systems to share electronic data because these systems were developed independently by different makers for use in different types of construction sites and to perform different types of work. In order to use information efficiently to gain the full benefits of such systems, it is vital to be able to transfer electronic data smoothly between construction information systems and between their sub-systems. This will also sharply reduce the cost of using construction information systems.

This paper considers the significance of and need for ways for multiple construction information systems of different kinds to exchange and share data, and proposes data exchange concepts. It also discusses the merits and demerits of the data exchange standards and describes the composition of them, and based on it, takes an earthwork compaction control system as a specific example to analyze the categorization and hierarchical structure of data in order to establish a data model as the foundation for the construction of data exchange standards.

The results of this study were proposed as part of the standardization activities of the ISO/TC127/WG2 (Earth-moving machinery – Worksite data controlled earth-moving operation) that are now in progress and will be studied to provide basic documents for the preparation of data exchange standards [1].

2. FUNCTION AND ROLES OF IT BASED CONSTRUCTION SYSTEMS

To create construction robots or automated construction systems or any other IT based construction systems (below called, “IT based construction systems”), their functions must go beyond controlling the operation of machinery to include interacting with the world of information. An IT based construction system should be equipped with interfaces to link it with the world of information and with the material world as shown in Figure 1 and with a function that translates meaningful content in each of these worlds so that it is understood in the other [2]. If this is impossible, an IT based construction system...
cannot automatically and autonomously do the work that people intend it to perform, because it fails to comprehend human intentions. Therefore, studying the interface to link an IT based construction system with the world of information is just as important as researching what kinds of work the IT based construction system will perform.

The part of an IT based construction system that is an interface with the world of information is a system built centered on IT technology and is called a construction information system. There have been many cases of automated construction system development where a big challenge that had to be overcome to create a final working system was the inability to efficiently and skillfully inform the machinery of human intentions. For example, an automated asphalt finisher that was developed in Japan could perform highly precise work by three-dimensional control of the screed, but during the work, it was necessary to provide pavement design data in detail using three-dimensional data. For normal work, pavement design data is usually provided on plane, longitudinal section, and lateral section drawings as data that the operator refers to during the work, but this meant that preparing and entering the three-dimensional data required to perform automated finishing was an excessively time-consuming task. To apply the system to actual work, it was necessary to write software to read in electronic data such as CAD data etc. or to perform data entry.

3. NEED TO EXCHANGE DATA BETWEEN DIFFERENT IT BASED CONSTRUCTION SYSTEMS

To widely use IT based construction systems for construction work it is of course essential to provide an interface between humans and IT based construction systems as explained above, but it is also necessary to guarantee conditions permitting accurate data exchange between different IT based construction systems. An interface between an IT based construction system and humans always depends on display and entry systems of some kind. This is true, because although a construction system can respond only to electronic data represented according a previous agreement of some kind, a human can understand text represented by ordinary characters, natural language, drawings, tables, images, moving pictures, and not electronic data, which means that every interface must have a translation function.

Characteristics of construction work relevant to the utilization of IT based construction systems are (1) it generally includes multiple (many) types of work, (2) construction work is work that is completed in a limited period of time, and (3) a necessary construction system is planned and created especially for each construction project. And it is predicted that because of the variation in construction machinery used to perform different types of work and the fact that they are supplied by different manufacturers, there will be construction systems with varying functions and that are used in different ways, so that (4) every construction system will have a unique interface. Normally, an engineer who is responsible for executing a construction work wants to do it with an integrated system in order to smoothly perform the series of work steps that constitute the work. Therefore, separate construction information systems must function as a single system to be integrated, and to provide this capability, it is essential that electronic data handled by all the construction information systems that are positioned as sub-systems of the integrated system can be exchanged by these individual sub-systems. It is also predicted that in more advanced automated construction systems, data representing the results of a prior work step will become entry data needed to perform a later step in the work. But this level of data linkages will only be possible if all construction information systems can exchange electronic data.

4. PROPOSAL OF DATA EXCHANGE STANDARDS

We believe that data exchange standards must be enacted as a basic method to achieve data exchange between different construction systems. In order to realize data exchange between different
systems, many requirements, such as cable connection, electrical connection, protocol and data contents, should be satisfied. Above all, the interoperability of data is the most essential and important. Therefore we focused on the data. Data exchange based on data exchange standards will be performed by the following procedure [3]. Figure 2 shows an example of the use of data exchange standards to exchange data between two different systems: the smallest unit of data exchange by construction systems. Data handled by a construction information system is, as explained below, generally defined by an application schema and a data dictionary. Figure 2 shows how data is transferred from System A on the left to System B on the right. The data transfer is done by converting the data to data based on data exchange standards (below called “standard format data”). Therefore, original format data in system A is converted to standard format data that is received by system B by referencing the data exchange standards. In system B, the standard format data is converted to system B’s original format data and used by System B. In order to perform such data exchange, it is essential to guarantee that the data in System A and in System B are both in a one-to-one correspondence with the data in the data exchange standards.

5. MERITS AND DEMERITS OF THE DATA EXCHANGE STANDARDS

It is assumed that using data exchange standards will increase the number of situations where systems can be used over the number of such situations without exchange standards, and the more situations where systems can be used, the greater their beneficial impact on the market. In other words, if exchange standards are not used, conversion software will be needed for each situation where data is exchanged between systems, and if data exchange standards are used, each system will be capable of exchanging data with all construction information systems if it is equipped only with conversion software for the data exchange standards. Needless to say, to use data exchange standards, accurate data exchange standards must be provided.

Preparing and using data exchange standards are expected to have the following useful benefits for parties playing various roles in the market.

- Suppliers (makers) of construction information systems will, by developing and supplying systems that comply with data exchange standards, gain opportunities to participate at sites where systems from different makers are used if the systems comply with data exchange standards. In other words, they will enjoy expanded business opportunities.
- Users of construction information systems can use systems supplied by different makers without being limited to the systems they now use, sharply expanding their freedom of choice.
- As a competitive market for the procurement of construction information systems is formed in this way, it is counted on to contribute to lower costs and higher quality and performance, spurring the development and wide use of these systems.

But on the other hand, it is also predicted that the preparation and use of data exchange standards will, of course, bring disadvantages.

- Because the standards must be created premised on present technologies or those that will be developed in the near future, once a set of standards is in operation, there is a danger
that it will unavoidably apply the brakes to the advance of technological progress or impede technological development. There is also concern that cases where there are existing technologies will incur great cost and trouble in order to adapt them to the standards. These points must be considered when preparing and applying standards.

6. COMPOSITION OF THE DATA EXCHANGE STANDARDS

Data normally consists of a number of data elements. If, in a case of few data with a simple composition, a data dictionary that stipulates each element is provided, the data may be usable, but generally, an application schema that stipulates the categorization and hierarchical structure of the data and the interrelationships between the data is necessary. A data dictionary stipulates definitions and attributes of data elements positioned in the application schema. The application schema is a conceptual schema obtained from a specific data model.

7. STUDY OF A DATA MODEL

The authors have taken information handled by a construction information system at an earthwork site to analyze and study the data model that will be the foundation of data exchange standards in order to construct an environment that permits the mutual exchange of data between construction systems: a capability that construction systems must have to be of any practical use.

In this chapter, figure 4, figure 5 and figure 6 are drawn in the UML (Unified Modeling Language) notation [4].

7.1 Target Range

The study of data exchange standards have been done focusing on the on-site construction work performed by construction machinery during actual work. The exchange of data throughout the execution of a construction project involves organizations, systems, and equipment in a variety of positions, but one simplified form can be shown by the model outlined in Figure 3.

To concentrate on data exchange in work site execution, the study first dealt mainly with data concerning the site information system (SIS) shown in the figure [2]. SIS corresponds to the on-site construction information system that is used in ordinary construction work.

The principal uses of SIS were hypothesized to be the use cases in Figure 4.

7.2 Listing Data in an Actual Construction System

The example of a construction information system that was selected was a system used to control embankment compaction work that is a part of earthwork actually performed in Japan, and the data items used for this purpose were listed. Table 1 shows this example.

It shows that these items consist of data concerning work planning or instructions, data concerning the machinery used, data concerning the state of machinery during the work, data concerning work results, and data used to judge whether the work results are suitable.
Study of the Concept of Data Model

Preparation

The data model that was prepared was the foundation for the preparation of the application schema of the data exchange standards, and it was necessary for it to be easy to understand and for it to reflect the state of work at work sites in order that an undetermined number of people who use it can gain a common understanding of the model.

Specifically, data centered on SIS used at a work site can, as shown in Figure 5, be broadly categorized as five kinds of data: basic project data, machinery management data, mission data, achieved work data, and construction checking data. This was concluded based on the on-site work contents and work process with reference to the data list described above.

There are also data in these different categories that are extremely closely related and their relationships are indicated by adding sub-categories such as “target data” for the work. At the machinery construction stage, data presenting the state of the work is consecutively produced, recorded, exchanged, and utilized during the work. Therefore, sub-categories that correspond to these (working state of construction machine, etc.) were described. It was also hypothesized that it would be necessary to handle “machine control data” when advanced work or automated work using information is done.

Results of the Study of the Data Model

Figure 6. shows the framework of the data model that was prepared.

This figure was prepared as the first proposal of a framework for the construction of the data model. In the future, the attributes of each class must be clarified by further studies performed with reference specifically to the ways that various kinds of construction information systems are used.

7.4 Results of the Study of the Data Model

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8. CONCLUSION

This paper has shown that the exchange of data between construction information systems must be achieved in order to make further progress in the introduction of construction robots and automated construction systems etc. and revealed that the following measures will achieve this goal.

• Taking measures based on data exchange standards is the best way to realize the exchange of data between construction information systems. It is counted on to provide manufacturers with new business opportunities and to give users improved freedom of choice, lower costs, and higher quality.

• Data exchange standards consist of an application schema and a data dictionary, and the application schema is developed from a data model.
The model of the framework shown in Figure 6 was presented as a proposal for a data model of on-site execution. A detailed data model presenting concrete data elements will be prepared and the application schema of data exchange standards based on this data model will be completed in the future. The results of this study were proposed as part of standardization activities by ISO/TC127/WG2 that are now in progress and will be studied to provide basic documents for use in preparing data exchange standards. The data dictionary also will be studied in this WG2.

9. ACKNOWLEDGEMENTS

The study described by this report was carried out with the generous advice and assistance of the members of standardization working group of the ISO/TC127/WG2 subcommittee of the JCMA of Japan. We also received valuable advice from Dr. Peyret of the LCPC in France and other experts taking part in ISO/TC127/WG2. The authors wish to express their sincere gratitude to them for their invaluable support.

10. REFERENCES


Report of the NIST Workshop on Data Exchange Standards at the Construction Job Site

by

Kamel S. Saidi, Alan M. Lytle, William C. Stone

ABSTRACT: The Building and Fire Research Laboratory of the National Institute of Standards and Technology, in cooperation with the Fully Integrated and Automated Technology (FIATECH) consortium, sponsored a workshop on data exchange standards at the construction job site in May 2003. The purpose of the workshop was to investigate the problem of exchanging sensor data at the construction job site. Some of the desired outcomes were to identify requirements for and barriers to sensor data exchange in construction, to identify and plan the steps required to establish raw sensor data-exchange standards, and to identify future research directions. A description of the workshop structure, agenda, and preliminary results are presented.

KEYWORDS: construction automation, intelligent job site, construction sensors, LADAR, data exchange standards

1. INTRODUCTION

The construction industry has indicated that knowledge of the status of a construction project is one of the most challenging problems faced by project management and jobsite personnel [1, 2]. Although construction measurement and sensing technologies and project information management software (PIMS) – such as scheduling and estimating software – have advanced considerably in the past 20 years, accurate and up-to-date knowledge of the current status of a construction project remains elusive.

New CAD technology is attempting to bridge the gap between scheduling and traditional CAD software thereby producing a new class of software technology known as 4D CAD. 4D CAD allows “visualization of the facility design and its changes over time and allows computer-based analysis of constructibility, cost, productivity, and other project performance variables dependent on an integrated analysis of time and space” [3].

However, both 4D CAD and other PIMS need to be supplied with updates from the jobsite about the state of the various construction activities, and at present these systems rely primarily on workers who manually enter up-to-date information. One of construction automation’s premises is to introduce advanced measurement and sensing technologies onto the jobsite in order to automate the updating process. Ubiquitous sensing with real-time construction process monitoring and control are the prerequisites for creating an intelligent jobsite [5].

The workshop brought together general contractors, construction equipment manufacturers, metrology instrument...
manufacturers, sensor and product model data exchange experts, and construction researchers.

The discussion was focused on the data exchange issues involved in seamlessly integrating future and existing measurement and sensing technologies (such as LADAR, GPS, RFID, total stations, temperature sensors, strain sensors, etc.) with construction software and other hardware in order to improve productivity, quality, and safety, as well as prepare for future sensing and automation challenges (such as deploying fully-automated machinery on the jobsite). Sensors and sensor data exchange were emphasized throughout the workshop.

Some of the desired outcomes from the workshop were to identify requirements for and barriers to sensor data exchange in construction, to identify and plan the steps required to establish raw sensor data-exchange standards, and to identify future research directions.

This report presents information contained in the keynote addresses and results of the working group breakout sessions.

2. WORKSHOP FORMAT

The workshop convened over a period of 2 days. A total of 24 non-NIST participants attended the workshop. Participants included representatives from 3 leading US engineering, procurement, and construction companies and 3 leading instrument and equipment manufacturers. In addition, researchers from 6 universities and 2 specifications organizations were present. NIST researchers included personnel from the Building and Fire Research Laboratory’s (BFRL) Materials and Construction Research Division and Building Environment Division, as well as personnel from the Manufacturing Engineering Laboratory’s (MEL) Manufacturing Metrology Division.

The workshop was divided into three sessions. Each session included 2 topical presentations, a breakout session, and a full group discussion.

3. DETAILED AGENDA

3.1 Day One

Day one began with an introduction by the NIST Building and Fire Research Laboratory director, Dr. Jack E. Snell.

The introduction was followed by a two-part questionnaire that asked the participants to describe their view of an “Intelligent Job Site,” and to state their personal desired workshop outcomes.

Following the administration of the questionnaire, Dr. William C. Stone, leader of the NIST Construction Metrology and Automation Group (part of BFRL), gave a presentation entitled “The Automated Construction Site: Data Exchange Problems” [6].

Dr. Stone’s presentation discussed some of the challenges faced by the US construction industry and how technology can address some of those challenges. In particular, Dr. Stone talked about developments in LADAR (Laser Detection and Ranging) sensor technology and how it can be used in construction. Other topics discussed in Dr. Stone’s presentation included:

- Robot positioning
- Object recognition
- Robot control
- Visualization
- Data management
- Barcodes
- RFID tags
- Smart Chips
- Long-range auto identification

Dr. Stone was followed by Mr. Harry Niedziadek, Architect of the Open GIS Consortium’s (OGC) Interoperability Program, who gave a presentation entitled “The Sensor Web Enablement Framework (Status and Plans for Sensor Web Technology at OGC)” [7].
Mr. Niedziadek first introduced the audience to the OGC and then discussed the Sensor Web Enablement (SWE) framework and concepts of its architecture, applications, and development plans. Mr. Niedziadek also touched on the relevance of the SWE framework to the intelligent jobsite. He stated that the SWE framework provides a common, open service for “tasking, monitoring, and collecting observations for any and all sensors” [7]. Mr. Niedziadek also suggested that the SWE framework would make “sensors just another resource in jobsite applications: safety, security, materials management, asset management, maintenance management, equipment status, construction monitoring, performance monitoring, etc.” [7].

Following the first two presentations the workshop participants were divided into 3 groups. Each group was presented with a list of questions regarding the intelligent job site and asked to discuss them.

The afternoon session of day one began with a presentation by Mr. Kang Lee, leader of the NIST Sensor Development and Applications Group (part of the Manufacturing Engineering Laboratory) entitled “The Smart Transducer Interface Standards (IEEE P1451)” [8].

Mr. Lee presented the work that has been done toward the development of the IEEE transducer interface standard (parts of which have already been established and published). In his presentation Mr. Lee stated that the P1451 standard provides “an industry wide, open standard” that can provide common analog, digital, and wireless “interfaces between sensors/actuators, instruments, microprocessors, or networks” [8].

Mr. Lee’s presentation was followed by Dr. Michael Botts of the University of Alabama at Huntsville. Dr. Botts presented a talk entitled “Sensor Model Language (SensorML): XML-Based Language for In-situ and Remote Sensors” [9].

In his presentation, Dr. Botts described SensorML as “an XML schema for defining the geometric, dynamic, and observational characteristics of a sensor” [9]. SensorML allows software and hardware to communicate with different sensors regardless of the manufacturer as long as both parties speak SensorML.

Dr. Botts presented the following possible benefits of SensorML to construction [9]:
- Standard descriptions of all sensors in the community
- Easier assessment and discovery of sensors
- Common software for all sensors
- Archive of embedded/mounted sensor capabilities decades from now
- “Intelligent Jobsite” – construction progress, “in-time alerts” (e.g. stresses exceeded), robotic construction
- Fusion of disparate data from 4D site

Following Dr. Botts’s presentation, the workshop participants were again divided into 3 groups. During the second breakout session the participants were presented with some guidelines and asked to discuss sensor interface and standardization issues related to construction.

3.2 Day Two

Day two of the workshop began with a presentation by Dr. Burcu Akinci of Carnegie Mellon University (Pittsburg, PA) entitled “Advanced Sensor Based Defect Detection and Management at Construction Sites” [10].

Dr. Akinci’s presentation discussed the following five issues [10]:

1. Scan Planning
2. Sensor Planning
3. Object Recognition
4. Integrated “Living” Project Models
5. Automating Defect Detection

Dr. Akinci showed through case studies that “total saturation” of a job site with LADAR is inefficient while sparse coverage may inadvertently miss relevant information. Having a plan in place that specifies when and from where each scan should be conducted can help produce more effective information [10].
Dr. Akinci’s presentation was followed by Dr. Kent Reed, leader of the Computer Integrated Building Processes group (part of BFRL). Dr. Reed presented a talk entitled “…now, for the rest of the story” [11].

Dr. Reed presented the case for integrated project delivery systems (PDS) that was developed by the Business Roundtable in 1997. That study showed that effective PDS resulted in an increase in return on investment for the owner, reduced project cost, and improved operability of the completed project.

Dr. Reed continued with a brief history of the efforts that have been expended on construction integration and interoperability research to-date and touched on some of these in more detail. He concluded with a list of issues that still need to be addressed in order to achieve true integration and interoperability in construction.

Following Dr. Reed’s presentation, the workshop participants were divided into 3 groups once again. The purpose of the last breakout session of the workshop was to discuss the issues that still need to be addressed in order to begin work on a standard/protocol/schema for sensor/instrument data exchange at the construction job site.

The ideas that resulted from the breakout sessions were then discussed among all the workshop participants.

Following the group discussion, Mr. Alan Lytle, Robotics Engineer at the NIST Construction Metrology and Automation Group gave a short talk about FIATECH in which he described the consortium, its recently published Capital Projects Technology Roadmap, and the planned Smart Chips pilot projects.

Mr. Lytle’s presentation was followed by an open discussion session during which the participants were asked to express their opinions freely and to discuss possible actions that could be undertaken.

4. RESULTS

This section presents preliminary results of the workshop’s breakout sessions and final open discussion session.

4.1 Breakout Session One Results

The following is a list of some of the questions and comments that came up during the first break out session on day one of the workshop:

- Need a life-cycle model of a construction job site and of the intelligent job site and of the processes involved in each (including information flows).
- Need to know what the sensor limitations are (e.g., can a sensor distinguish between a painted wall and an unfinished one?)
- Automating the collection of data at the job site is critical.
- What will be the organizational challenges of achieving the intelligent job site?
- Showing the cost benefit of implementing new technologies is critical to the owner. How will that be overcome?
- A sensor can become just like another project resource on the intelligent job site.
- What is the latency period in “real-time” data exchange at the intelligent job site and how will that be handled?
- What will the wireless networking issues be and how will they be solved (e.g., security of the data and coverage area interference)?
- Material tracking remains a very big problem on the current construction job site. How will that be solved on the intelligent job site and how can it be addressed today?

4.2 Breakout Session Two Results

The following is a list of some of the questions and comments that came up during the second break out session on day one of the workshop:

- Construction equipment manufacturers would prefer to buy sensors that are robust enough rather than developing their own.
- EPC contractors will not invest in an expensive technology because the business case is not there.
- Most people in the AEC field will not be interested in low level technical details.
addressed in IEEE 1451. IEEE 1451 and SensorML are complimentary standards/protocols, but the overlap should be clearly defined.

- Having a standard for sensor data exchange may encourage people in the construction industry to use more sensors.
- If every component has sensors on it, does it improve the capability to construct and improve the constructed product, or both?
- The format of the sensor data must be compatible with standard software.

4.3 Breakout Session Three Results

The following is a list of some of the questions and comments that came up during the break out session on day two of the workshop:

- Standards empower vendors and sensor data exchange standards will empower the sensor industry.
- Sensor manufacturers need a consortium to help in the standardization effort.
- As an example, there are currently no standards for LIDAR’s.
- The construction industry is too conservative and thus sensor manufacturers must take the lead in the standardization effort and they must present case studies to the construction industry to get proper buy-in.
- Standards can both promote and prevent innovation.
- A sensor can be any device that collects data (including humans).
- What is the difference between data and information?
- Overcoming the technological barrier to developing a sensor data exchange standard will be easier than overcoming the political barriers.
- Need to model the data exchange requirements during the entire life-cycle of a construction project.
- The standard should consider both the sensor user and sensor manufacturer points of view.

4.4 Open Discussion Session Action Items

The following is a list of action items that were developed during the open discussion session on day two of the workshop.

- Analyze the potential merging of 1451 and SensorML and provide a short report to interested parties
- Investigate the formation of an expert group to work within the OGC environment
- Initiate a forum for the sharing of relevant information related to the workshop
- Match our understanding of construction-related LADAR use with the GIS/Remote-sensing community (does the current schema in SensorML meet the need?)
- Publish a white paper outlining driving requirements (with buy-in and prior standards research) to suggest some initial ideas to OGC
- Develop a description of an intelligent jobsite
- Prioritize the “information” needs on the job site and use the described need as a basis for selecting the initial sensor(s) to target for the standards effort
- Investigate whether the data exchange standards effort is targeted at sensors/instruments for the specific construction process or for the project life-cycle
- Define a “sensor” as applicable to the data exchange standards effort
- Define “data” (information) as applicable to this effort
- Consolidate literature on cost analysis of automation in construction

5. CONCLUSIONS AND FUTURE WORK

The workshop on data exchange standards at the construction job site was held on May 29 and 30, 2003 at NIST in Gaithersburg, MD. The workshop brought together people from the construction industry, equipment manufacturers, and research institutions (among others) to discuss the barriers and challenges to sensor data exchange in construction and the steps required to establish raw sensor data-exchange standards. The preliminary results of the workshop were presented above.

Future work includes analyzing the workshop results further and publishing the findings in a final report. In addition to the action items presented above, the findings from the final report will also be investigated and a research roadmap will be developed.
6. REFERENCES


Construction Enterprise Resource Planning Implementation: Critical Success Factors – Lesson Learning in Taiwan

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ABSTRACT: Enterprise Resource Planning (ERP) is the latest high-end solution information technology has lent to business application. Enterprise resource planning systems are highly complex information systems. The implementation of these systems is a difficult and high cost proposition that places tremendous demands on corporate time and resources. Many ERP implementations have been classified as failures because they did not achieve predetermined corporate goals. The paper identifies main success factors critical to a successful implementation. A summary of successful ERP implementation is presented based on lesson learned from the interviews with experts and discussed in terms of these key factors.

KEYWORDS: Enterprise resource planning; Construction Industry; Critical success factors

1. INTRODUCTION

The construction business environment is dramatically changing. Construction enterprises today face the challenge of increasing competition, expanding markets, and rising customer expectations. This increases the pressure on companies to lower total costs in the entire supply chain, shorten throughput times, drastically reduce inventories, expand product choice, provide more reliable delivery dates and better customer service, improve quality, and efficiently coordinate global demand, supply, and production. As the business world moves ever closer to a completely collaborative model and competitors upgrade their capabilities, to remain competitive, organizations must improve their own business practices and procedures. Companies must also increasingly share with their suppliers, distributors, and customers the critical in-house information they once aggressively protected. And functions within the company must upgrade their capability to generate and communicate timely and accurate information. To accomplish these objectives, companies are increasingly turning to enterprise resource planning (ERP) systems. ERP provides two major advantages that do not exist in non-integrated departmental systems: (1) a unified enterprise view of the business that encompasses all functions and departments; and (2) an enterprise database where all business transactions are entered, recorded, processed, monitored, and reported. This unified view increases the requirement for, and the extent of, interdepartmental cooperation and coordination. But it enables companies to achieve their objectives of increased communication and responsiveness to all stakeholders. Limited study has been conducted in the ERP implementation of construction industry, with most research consisting of case studies in other industries. Furthermore, critical success factors for enterprise resource planning implementation will be different than others because the characteristic of construction industry is different than others industries. Therefore, the paper present main factors critical to a successful implementation for construction industries based on the interview and literature review.

2. PROBLEM STATEMENTS

ERP systems implementation is a long-term program, not a short-term project that is finished just after system installation. Also, the price of ERP system is very expensive. Once organizations have purchased ERP packages from external vendors, a project team including external consultants and internal employees will be setup. However, the construction business is operated around projects. Each project is an end production to be delivered
and is expected to be completed on time and within budget. Therefore, the implementation of core methodology for ERP is different since the production line is totally different. Furthermore, about 90 percent of ERP implementations are late or over budget and ERP implementation success rate is only about 33%. The steep difference of ERP systems implementation success rates between construction industry and other industries produces a need of research to examine general and specific-to-construction critical success factors.

3. RESEARCH METHODOLOGY AND FRAMEWORK

This paper discusses what successful factors specialty to enterprise resource planning system implementation to construction enterprise. In current practice in Taiwan, many construction enterprises start to consider the implementation of ERP system for their enterprise. There are two construction companies that implement their ERP system successfully selected as case studies. One uses SAP R/3 system and another uses IFS system. The research consisted of conducting a series of one-to-one interview with experienced participants. The results of interview are summary with the others related reports and literature. The aim of this paper is to unveil what successful factors may contribute to system implementation special to construction industry.

4. CRITICAL FACTORS FOR SUCCESSFUL ERP IMPLEMENTMENT

Implementing an ERP system is not an inexpensive or risk-free venture. In fact, 65% of executives believe that ERP systems have at least a moderate chance of hurting their businesses because of the potential for implementation problems. It is therefore worthwhile to examine the factors that, to a great extent, determine whether the implementation will be successful. Numerous authors have identified a variety of factors that can be considered to be critical to the success of an ERP implementation. The most prominent of these are described below (see Figure 1).

4.1. Clear understanding of strategic goals

ERP implementations require that key people throughout the organization create a clear, compelling vision of how the company should operate in order to satisfy customers, empower employees, and facilitate suppliers for the next three to five years. There must also be clear definitions of goals, expectations, and deliverables. Finally, the organization must carefully define why the ERP system is being implemented and what critical business needs the system will address.

4.2 Organizational change management

Implementing an ERP system involves reengineering the existing business processes to the best business process standard. One of the principal reasons why ERP and other large technologically sophisticated systems fail is that organizations simply underestimate the extent to which they have to change and re-engineering the existing business processes in order to accommodate their purchase. ERP systems are built on best practices that are followed in the industry. All the processes in a company must conform to the ERP model. Dimensions concerning business process reengineering are: (1) Company’s willingness to reengineering; (2) Company’s readiness for change; (3) Company’s capability of reengineering; and (4) Communication. Prior studies claimed that the more willing an organization is to change, the more successful the implementation. There should exist the trust between top management and the staff within the company, which would facilitate the change process. While communication is another determinant factor affecting successful BPR implementation in that BPR is a radical redesign of the company’s current culture, structure, and process. If people within the company were not given enough information about the purposes of BPR, they would feel uncertainty about their jobs, which can impede the progress of reengineering. Management should answer every employee question and held company-wide meetings to make the strategy understood by every people.

4.3 Top management Support

Many study have stressed the importance of top management support as a necessary ingredient in successful ERP implementation because successful implementations require strong leadership, commitment, and participation by top management. Since executive level input is critical when analyzing and rethinking existing business processes, the implementation project should have an executive management planning committee that is committed to enterprise integration, understands ERP, fully supports the costs, demands payback, and champions the project. Moreover, the project
should be spearheaded by a highly-respected, executive-level project champion.

4.4 Excellent project management

ERP systems implementation is a set of complex activities, involving all business functions and often requiring between one and two years of effort, thus companies should have an effective project management strategy to control the implementation process, avoiding overrun of budget and ensuring the implementation within schedule. There are six major parts of project management: (1) having a clear implementation strategic, (2) having a formal implementation plan, (3) a realistic time frame, (4) having periodic project status meetings, (5) having an effective project leader who is also a champion, and (6) having project team members who are stakeholders. The formal project implementation plan defines project activities, commits personnel to those activities, and promotes organizational support by organizing the implementation process. Having a realistic time frame is very important. If the target completion time schedule were unrealistically short, the pressure to rush through would result in the implementation being carried out in a haphazard manner. On the other hand, if the implementation delayed for too long, people would tend to lose faith and/or patience, which also will result in low morale and resistance. Conducting periodic project status meetings in which each team member reports progress and problems is an invaluable means for evaluating the progress of the ERP implementation. Selecting the right project leader is also important for the project implementation success.

4.5 Data accuracy

Data accuracy is absolutely required for an ERP system to function properly. Because of the integrated nature of ERP, if someone enters the wrong data, the mistake can have a negative domino effect throughout the entire enterprise information system. Therefore, educating users on the importance of data accuracy and correct data entry procedures should be a top priority in an ERP implementation. ERP systems also require that everyone in the organization must work within the system, not around it. Employees must be convinced that the company is committed to using the new system, will totally changeover to the new system, and will not allow continued use of the old system. To reinforce this commitment, all old and informal systems must be eliminated. If the organization continues to run parallel systems, some employees will continue using the old systems.

4.6 Full-time implementation team

Full-time implementation team should be selected to lead the implementation action. ERP implementation teams should be composed of top-notch people who are chosen for their skills, past accomplishments, reputation, and flexibility. These people should be entrusted with critical decision making responsibility. Management should constantly communicate with the team, but should also enable empowered, rapid decision making. The implementation team is important because it is responsible for creating the initial, detailed project plan or overall schedule for the entire project, assigning responsibilities for various activities and determining due dates. The team also makes sure that all necessary resources will be available as needed.

4.7 Extensive education and training

Education and training are probably the most widely recognized critical success factor, because user understanding and buy-in is essential. ERP implementation requires a critical mass of knowledge to enable people to solve problems within the framework of the system. If the employees do not understand how a system works, they will invent their own processes using those parts of the system they are able to manipulate. The full advantages of ERP cannot be realized until end users are using the new system properly. To make end user training successful, the training should start early, preferably well before the implementation begins. Executives often dramatically underestimate the level of education and training necessary to implement an ERP system as well as the associated costs. Top management must be fully committed to spend adequate money on education and end user training and incorporate it as part of the ERP budget. It has been suggested that reserving 15–20% of the total ERP implementation budget for training will give an organization an 90% chance of implementation success. All too often, employees are expected to be able to effectively use the new system based only on education and training. Yet, much of the learning process comes from hands-on use under normal operating conditions. Thus, a designated individual (preferably the project leader) should maintain ongoing contact with all system users and monitor
the use of, and problems with, the new system. There is also a need for post-implementation training. Periodic meetings of system users can help identify problems with the system and encourage the exchange of information gained through experience and increasing familiarity with the system.

4.8 Multi-sites Consideration

Multi-site implementations present special concerns. The manner in which these concerns are addressed may play a large role in the ultimate success of the ERP implementation. The desired degree of individual site autonomy may be a critical issue which depends on two factors: (1)the degree of process and product consistency across the remote sites, and (2) the need or desire for centralized control over information, system setup, and usage. One of the objectives of an ERP implementation may be to increase the degree of central control through the implementation of standardized processes. Alternatively, the implementation may be undertaken in order to provide the remote sites with capabilities that allow them to fine tune their processes to their unique situations. Another complexity in dealing with multi-site implementations is the degree to which the culture of the organization differs between sites. The fundamental issue here is one of corporate standardization versus local optimization. Corporate standardization brings with it simplified interfaces among diverse parts of the organization, ability to move people and products between sites with minimal disruption, and relative ease in consolidating data across the entire organization. On the other hand, local optimization may result in more effective and efficient operation and may reduce costs. Perhaps the most difficult decision to be made in a multi-site implementation is the question of cutover strategy. The organization must choose between an approach where the implementation takes place simultaneously in all facilities or a phased approach by module, by product line, or by plant with a pilot implementation at one facility. With a large outlay of cash up front for software, hardware, and the project team, the company may want a simultaneous implementation in order to recoup its investment as quickly as possible. In a multi-site implementation, a phased approach is generally considered to be preferable. This is partly because the success or failure experienced in the first attempt at implementation often decides the fate of the entire project. Thus, the management team can gain momentum by selecting a pilot site that has a high likelihood of success. And if ERP is installed in a phased approach module by module, department by department, or plant by plant—the lessons learned at early sites can make the implementations at later sites go smoother.

4.9 Effective performance measures

Effective performance measures that assess the impact of the new system must be carefully constructed. Of course, the measures should indicate how the system is performing. But the measures must also be designed so as to encourage the desired behaviors by all functions and individuals. Such measures might include on-time deliveries, gross profit margin, customer order-to-ship time, inventory turns, vendor performance, etc. Project evaluation measures must be included from the beginning. If system implementation is not tied to compensation, it will not be successful. For example, if all managers will get their raises and bonuses next year even if the system is not implemented, successful implementation is less likely. Management, vendors, the implementation team, and the users must share a clear understanding of the goal. If someone is unable to achieve agreed-upon objectives, they should either receive the needed assistance or be replaced. When teams reach their assigned goals, rewards should be presented in a very visible way. The project must be closely monitored until the implementation is completed. The system must be forever monitored and measured. Management and other employees often assume that performance will begin to improve as soon as the ERP system becomes operational. Instead, because the new system is complex and difficult to master, organizations must be prepared for the possibility of an initial decline in productivity. As familiarity with the new system increases, improvements will occur. Thus, realistic expectations about performance and time frames must be clearly communicated.

4.10 Consultant Vendor Support

Consultant vendor play a important role in the ERP implementation. Most local companies purchase ERP packages from foreign ERP vendors and ERP represent the best-practice processes that is different from Taiwan’s organizational business process, thus, it’s necessary and important to get the consultant vendor support. Three dimensions of consultant vendor support are classified: (1) Service response time of the software vendor; (2) Qualified
consultants with professional knowledge in both enterprises’ business processes and information technology including consultant vendors’ ERP systems; and (3) Participation of vendor in ERP implementation. It’s important for the consultant vendor’s staffs to be knowledgeable in both business processes and ERP system functions. Also, the consultants should possess good interpersonal skills and be able to work with people. Software vendors should be carefully selected since they play a crucial part in shaping the ultimate outcome of the implementation.

5. CONCLUSION

This paper aims to improve understanding of critical factors affecting ERP implementation success in construction industries. The interview of four construction companies in Taiwan implementing the ERP system is made to summary and discuss in terms of these key factors for successful ERP implementation. However, due to the small sample size in the survey, there are some limitations in the generalization of the research results to a larger population. Meanwhile, ERP implementation is not a short-term project lasting only two or three months, but a long-term program which may last for one or several years. Factors affecting ERP implementation are complex and abundant, thus many researchers conduct case study only to find out some specific problems with ERP implementation. Undoubtedly, detailed case study is a powerful tool to solicit important issues disregarding to its disadvantage of generalization problems. Thus, combining detailed case study and a large survey would be an helpful method to improve the successful ERP implementation special for the construction industries.

6. REFERENCES


A. Angerosa (1999), The future looks bright for ERP, APICS - The Performance Advantage (October) 5–6. 


C. Dillon (1999), Stretching toward enterprise flexibility with ERP, APICS—The Performance Advantage.


G. Langenwalter (2000), Enterprise Resources Planning and Beyond: Integrating Your Entire Organization, St. Lucie Press, Boca Raton, FL.

J. Krupp (1998), Transition to ERP implementation, APICS - The Performance Advantage.


Figure 1. Critical Success Factors of ERP System for Construction industry.
Study of Methods of Sharing Information Handled at the Maintenance and Management Phase

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ABSTRACT: As a result of the rapid advance of information technology (IT) and development of CALS/EC in recent years, the MLIT (Ministry of Land, Infrastructure and Transport) and other organizations that order public works projects now deliver the results of survey and design work and completed work drawings as electronic data and can now directly handle information related to construction projects as electronic data. Of these, work at the maintenance stage is expected to benefit the most from the use of electronic information because it permits the collection of preliminary study, surveying, design, and execution information. And although GIS and other data bases are being constructed, data bases that have been construction and operated up till now have been constructed as separate systems that cannot share and link their information. Linking data bases is counted on to permit integrated handling of their information and linked searching and block updating of the data bases to increase their effectiveness among the project groups that have systems.

This report describes rules applied to share and link information in different databases so that their users can exchange their data and thereby synergistically receive the benefits of the electronic handling of information. It also discusses the effects of linking information by comparing present and future conditions based on a work process analysis.

KEYWORDS: CALS/EC, Maintenance and Management, Sharing Information, Electronic Delivery.

1. INTRODUCTION

In Japan, through efforts to introduce CALS (Continuous Acquisition and Life-cycle Support)/EC (Electronic Commerce), the MLIT has, since April 2001, approved and introduced the submission of the results of design work and completed drawings of work in a form prepared by recording CAD, application files, PDF or other electronic files on electronic media (electronic delivery) instead of on printed documents that include conventional drawings and written reports. This is counted on to permit project participants to easily use electronic data that has been delivered and to encourage the creation of data bases and data handling systems.

The purpose of the rules for data exchange proposed by this paper is to permit linking and sharing of data by carrying out the minimum level of improvement instead of reconstructing data bases when progress in data base development requires that information be linked and shared between a variety of data bases.

2. UTILIZATION OF INFORMATION AT THE MAINTENANCE STAGE: REQUIREMENTS AND CHALLENGES.

The maintenance of public works structures after the completion of public works projects is neither as automated nor as mechanized as work performed at the construction stage, with human labor accounting for most of this work. For this reason, inspection and repair plans, maintenance related plans, instructions, and records of work results are retained on paper (print-outs, etc.). As these stored records are prepared daily and their volume grows steadily, searching for and referencing past records in order to utilize them becomes an extremely laborious task. Therefore, we hope that recording these types of information in electronic form and incorporating them in data bases and data systems will increase the efficiency of searching, referencing, and other data processing.

Normally, converting paper records to electronic form is a laborious and costly process. The introduction of electronic delivery of completed drawings of work will permit electronically delivered data representing completed work and quality and construction
management that are work records to be registered in a data base to be used for maintenance without modification. Because this will simplify the task of converting the information used to electronic form, it is counted on to encourage the development of new data bases.

But because data bases and data processing systems are developed and introduced for the convenience of system owners and users, their development ranges and introduction periods vary. This results in the provision of a variety of finely demarcated data bases instead of the construction of single data base that can be applied to all work. Because these groups of data bases are developed by different developers, they are constructed as independent systems. When data bases are developed this way, the only restrictive conditions are the specifications demanded by the user, mainly regarding the screen configuration and functions, while the data base configuration and the data specifications are determined to suit the vendors. The key problem in developing a data base, particularly one used at the maintenance stage, is to find a way to simplify the preparation of print-outs. It essential that drawings and text prepared by a data base user during work conform with the print-outs and that they are processed efficiently until they are printed, but because data base users lack the specialized knowledge needed to know what form of data to use in order to realize this function, specific functions are not presented.

A characteristic of electronic data is that, unlike text information recorded on paper, it can be reused; not used only one time. For example, one data base can be accessed from another data base to search for and refer to needed information (electronic data) that can be combined, then displayed or output (Figure 1). Data in data bases must be shared and linked to realize this function.

3. DATA EXCHANGE RULES

To share and link electronic data in different systems and data bases, it is important to establish rules governing data exchange in a case where data is transferred between two data bases without prioritizing the structure of each data base or the methods each uses to process its data. This means that it is possible to develop a new data base that can easily share and link data by prioritizing its structure, but when dealing with an existing data base, it is necessary to carry out extensive modification to prioritize its structure and this is very costly. So when sending data to a data base whose data is to be linked and shared, if the data is exchanged after conversion to data that can be easily comprehended by the other data base, the data can be shared and linked with only slight modification of the data base and at low cost.

Specifically, the conversion function that operates when data is exchanged sets the rules for data conversion, and it is not necessary to develop an omnipotent conversion system.

Although an omnipotent conversion system can exchange data between data bases whose data are shared and linked at the time the systems were developed, a new conversion system (for example, version up) must be installed to exchange data with data bases developed at a later date, incurring new development costs every time data is shared and linked with a more recently developed data base. If data exchange rules have been established in advance, the data base is equipped with a conversion system that conforms with the exchange rules during development. And because the exchange rules also apply to a data base that is developed later, data can be exchanged without upgrading the conversion system, so development costs need not be incurred to exchange new data.

![Figure 1. Linked and Shared Use of Different Data Bases.](image1)

![Figure 2. Image of Data Exchange between Data Bases.](image2)
Then what are the basic technologies necessary for comprehensible data exchange with other data bases? If the configuration and structure of the data that is exchanged and if the definitions and formats of the data elements are decided, data can be recognized even when it is exchanged. So as a way to visualize the configuration and structure of data and relationships between data, the application schema is assumed to be uniformly confirming the definition and format of data elements in element units and a data dictionary is prepared and stipulated, permitting data exchange necessary to share and link the data.

And if data exchange rules are standardized, it is possible for all kinds of data bases and systems to share and link data. The targets of the standardization are a conceptual data model that organizes all information used at the management stage and data exchange rules (application schema, data dictionary) prepared with reference to this model.

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### 3.1 Application Schema

The application schema classifies the electronic data handled by the data bases and systems by category to present the stratified structure (hierarchical relationship) of the relationships and links between data. Because it can be used to visualize the form of data that could not be presented by the program language during data base development, it can contribute to mutual understanding between data base users (owners) and developers. Therefore, because the data configuration can be developed without dependency on the development (creation of a black box), data bases can be expanded to operate more efficiently even by other developers. Here the application schema is presented on a UML (Unified Modeling Language) class diagram.

And the application schema is discussed by the ISO/TC211 that handles GIS (geographic information systems).

![Figure 4. Example of an Application Schema (GIS)](image)

### 3.2 Data dictionary

The data dictionary is, if we liken the data to a language, used as a translation function that allows data bases that exchange data to understand the meaning of each other’s data. The contents of the data dictionary are data element names, definitions, formats, units, qualities, and relationships with the application schema.

And the data dictionary is discussed by the ISO/TC204 that handles ITS (Intelligent Transport Systems).

![Figure 5. Example of a Data Dictionary (ITS)](image)

### 3.3 Conceptual data model

Almost all types of information handled at the maintenance stage in Japan are information items
and contents on print-outs. The print-outs are prepared for each necessary work unit (date, period, range, work type, personnel, etc.) based on a maintenance task and work categorization system. Because the contents of each type of task and work can be understood by referring to a print-out, there are many similar or related tasks and work that are similar to items on the print-outs. This means that although work has been systematically organized, information items are not systematically organized. Information must be systematically organized in order to standardize the data exchange rules.

The conceptual data model is a reference model that clarifies the scope of the standardization (range, purpose, effects, etc. of the standardization) of the types of information used at the maintenance stage. This means that the conceptual data model plays a role as an overall map (bird’s eye view) to study the standardization range or to remove overlapping work when performing detailed standardization (preparation of the application schema).

It is prepared by systematically categorizing data on print-outs used for maintenance work considering the quality of the data, the work, person preparing the data, timing of the preparation etc.

4. CASE STUDY

Here, maintenance work using the data exchange standards is verified taking consultation with local residents, responding to and processing their complaints, and providing them with information concerning roads as a sample of processing work.

4.1 Services verified

Daily inspections of roads by road managers in Japan are performed about once a day. These inspections are generally done by inspectors visually examining the road from a patrol car, because of restrictions on the time the work can be done. It is, therefore, difficult to carry out detailed inspections. As a result, road managers are forced to receive, respond to, and process almost daily complaints about the roads from local residents and those who live beside the roads.

However, through hearing residents’ complaints, consulting with them, and providing information, road managers are often able to obtain useful inspection information.

For example:
- Roads signs are hard to see because they are covered by roadside trees.
- Water is overflowing a roadside ditch.
- Cars crossing a joint on the bridge make a loud noise.

These and other complaints support tree trimming, roadside ditch cleaning, and other maintenance, and also support the planning of bridge joint replacement work.

Till now, the tasks involved in consultations with residents have included recording and storing the results on print-outs, but because it is troublesome and time-consuming to search and refer to the necessary records (information), it has made a very small contribution to planning maintenance. So various offices are now taking steps to convert records of the handling of consultations with residents to electronic data to construct data bases and systems. Where the goal is to reduce the quantity of print-outs stored (paperless office), the data base is constructed using a general purpose spread sheet application. And at work places where the goal is speeding up processing residents’ consultations by searching for and referring to records of past consultations, the data base is constructed using a separately developed system suited to the flow of the work.

Because the number of consultations or complaints and the method of responding to them differ at each work place even though the types of information entered—requests for consultations and complaints from residents—are identical, the required specifications, development scope, functions, and configuration of each data base or system differ, and mutual links between data bases are not considered.
Using data exchange standards to link and share data between these data bases and systems would obtain the following benefits.

- If an upper level body with jurisdiction over many work places can transmit and receive electronic data to and from data bases at other work places, it can combine and refer to data, permitting statistical handling such as the categorization of resident’s consultations, clarifying the state of their projects and supporting project planning.
- Work place A can, by exchanging electronic data with data bases at work place B, process its work more efficiently by searching for and referring to similar information.
- If the process of responding to a resident’s complaint originally received by work place A has a ripple effect on work place B (example: construction noise), information can be shared during the process, so that work place B does not have to prepare initial data and data is not recorded more than once.
- It is possible to exchange data about residents’ consultations and complaints in data bases with other maintenance work support data bases (example, patrol support data base) mutually improving the efficiency of work. This service is shown in Figure 7.

4.2 Application schema, data dictionary

The data exchange standards that have been prepared by abstracting the data handled by this service based on a conceptual data model and by considering the process of responding to residents requests for consultations and their complaints and the way the data will be used are shown on the figures and tables described below.

The structure of the application schema was established by categorizing classes according to the situation that created the information (reception, approval, response, answer, hand-over) to simplify referencing from other services. Linkages between classes were constructed accounting for frequency and timing of data creation and for expandability to other services.

In the data dictionary, priority in naming the data elements was placed on names used generally nationwide as opposed to names used only in specified regions, and the attributes of the data elements were prepared with reference to road communication standards studied in the ITS field.

5. CONCLUSIONS

The data exchange standards proposed by this report will soon be applied to actual data bases in order to verify their usefulness and effectiveness. If the anticipated results are obtained, expanding them to other services in the future will be considered.

In Japan, social capital that are civil engineering structures (infrastructure) are generally provided and in the future, their maintenance and asset management will be the core issues. We hope that the data exchange standards will be indices used to create electronic information concerning maintenance in order to absolutely minimize the cost of this future maintenance work.

6. REFERENCES

1)ISO/DIS 19109, Geographic information – Rules for application schema. ISO/TC211
Figure 8. Data Exchange Standards Suited to a Residents’ Consultation and Complaint Response Service (Summary).
Monitoring Lifting Equipment for Automated Progress Control: A Feasibility Study

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ABSTRACT: Reliable and timely information describing up-to-date performance is a prerequisite for effective management of construction. Existing methods for on-site data collection are labor-intensive, subjective, and the data are frequently available only after activities have been completed. Monitoring of the main lifting equipment on construction sites can provide real-time, low-cost and objective data for interpretation within an APPC system. This paper reports on a field study conducted monitoring a tower crane employed in construction of a hybrid cast-in-place and precast concrete structure. Data describing the load weight, the hook height and the position of the hook in the building have been collected for multiple occurrences of different activity/building element combinations (including column formwork, slab formwork, pouring concrete beams, pouring concrete slabs, and reinforcing columns). A set of distinguishing characteristics of crane operations has been identified for computer-automated identification of the construction activities performed using the crane. A rigorous comparison of the potential values of each characteristic, for each activity type, has led to the conclusion that the characteristic values alone are insufficient for distinguishing between different activities. However, when the activity location is considered in the context of the building’s geometry and construction schedule, the activity can be identified almost all of the time. The geometry and schedule are provided in the format of an electronic Building Project Model. In this way, a set of interpretation rules capable of interpreting the data monitored in real time can be compiled. Useful information concerning the construction process can be reported, including the overall actual start and finish times of an activity, its duration, and the net time that the crane was employed for it.

KEYWORDS: Automated data collection; Building project model; Construction cranes; Project control.

1. INTRODUCTION

Reliable and timely information describing up-to-date performance is a prerequisite for effective management of construction. Existing methods for on-site data collection are labor-intensive, subjective, and the data are frequently available only after activities have been completed. Given this state of affairs, automation of on-site monitoring holds the potential to significantly improve the degree of managerial control that can be applied in construction. A general framework has been proposed for automating both

● on-site monitoring of construction activities, and

● interpretation of the data collected.

The framework is called Automated Project Performance Control (APPC). The principles for APPC were set out by Navon and Goldschmidt [Navon 2003a]. Field experiments were conducted in automated monitoring of construction workers [Navon 2003a] and earthmoving equipment [Navon 2003b].

Following these precedents, Sacks et al. recently proposed that monitoring building construction equipment holds the potential to provide significant data for APPC [Sacks et al. 2002]. The proposal is based on two observations: firstly, nearly all of the materials and components for a building are lifted into place by equipment, such as tower and mobile cranes, concrete pumps, hoists, etc. and secondly, collecting the raw data by tracking and recording the activity of construction cranes is technologically straightforward. The primary challenge in implementing a system is to automatically interpret the raw monitoring data to identify the activities that the equipment has performed. This paper reports on the results of research conducted with the goal of proving the feasibility of building knowledge-based software capable of performing...
the necessary interpretation. The following sections describe the conceptual approach and the proposed system process flow. Next, the characteristics of crane operations, as observed in a field study on construction of a reinforced concrete office tower, are identified. The relationship between specific value sets for the characteristics and the construction activities performed using the crane form the key to distinguishing between the different activities. The feasibility of interpretation using software is demonstrated through an analytical process in which distinct characteristic property filters are assembled for each distinct activity. Lastly, the potential for such a system to support automated reporting of activity resource consumption, durations, etc., is explored.

2. PROJECT ACTIVITY MONITORING SYSTEM

The monitoring system architecture is shown in figure 1. Apart from the raw data feed from the construction equipment, the system relies on project information stored in a building project model [Sacks et al. 2003, Sacks] and a knowledge-base.

![Diagram](image)

Figure 1. System overview.

The knowledge base includes data for calibration of the system for auxiliary equipment such as concrete buckets, lifting straps, etc., whose height and weight must be considered in interpreting the raw data. It also encapsulates the knowledge about typical characteristics of crane operations for different building activities. For example, in pouring concrete, the crane motion while loaded always originates outside of the building perimeter and ends within the building perimeter; when stripping forms, the direction is opposite. One component of this knowledge is a set of typical parametric ‘work-envelopes’, which define the possible locations of the crane hook during execution of the respective basic activities for each building element type. The element-basic activity (EBA) envelopes and their use are described in section 5.2 below. Volumetric envelopes are also defined for well-defined loading zones on the site, such as a delivery bay for concrete mixers, storage areas, etc.

The building project model comprises a full object based definition of the building project, including 3D geometry, a schedule of planned construction activities and details of the resources (equipment, materials and labor).

The interpretation module functions in three distinct stages. The first task is to distinguish between the different cycles of crane operation, which is done by identifying load changes on the hook. These occur at loading stations and at release stations. Typically, there is no motion at the stations. Some activities, such as concrete pouring, may have multiple release stations in each cycle. If auxiliary equipment (such as a concrete bucket) is attached over a series of cycles, the load on the hook during travel after the last release point of each cycle does not reduce to zero (in these cases, the activity can sometimes be identified by associating the minimum load at the end of each cycle with the weight of a piece of auxiliary equipment). Next, each cycle, with one or multiple release stations, is identified and associated with a specific basic construction activity performed on a specific building element. The feasibility of this step is the subject of the following sections. Lastly, the results are compiled and summed to a level of detail appropriate for comparison with the planned values for activity durations and labor and material consumption rates.

The outputs – activity durations, project progress, equipment usage rates and material consumption data, etc. – are detailed in section 5 below.

3. FIELD STUDY

A field study was conducted during the construction of a hybrid cast-in-place and precast concrete high-rise office building. A tower crane fitted with the proprietary ‘Dialog-Visu’ and ‘Top
Tracing’ monitoring systems was used, which provides hook height and load weight, the angle of the boom and the distance of the carriage from the mast [Potain]. The building consists of a reinforced concrete core formed using a self-climbing formwork system, a column and beam perimeter frame formed using purpose made steel shutters, and slabs built with hollow-core precast planks (figure 2). All of the concrete was poured using two tower cranes.

Figure 2. Field study building.

Two specific technical problems had to be overcome in collecting the raw data: accuracy and storage volume. An approximation algorithm was developed to correct the location data for bending of the crane mast, thus improving the location accuracy. The problem of data storage was addressed by identifying significant operating characteristics, including points of loading and unloading in real time, thus obviating the need to record all of the interim data at short time intervals.

From a technological point of view, the equipment necessary for collecting the data automatically is available (sensors and data loggers). In the field study, records of hook weight and location through time were collected for all of the typical basic activity types. The data were translated from the cranes monitoring system’s native form into the building’s local Cartesian coordinate system. The basic activities are listed in Table 1 together with the list of building elements on each floor. The sequentially numbered cells indicate element specific basic activities that occurred in the project (the gray cells did not occur).

4. INTERPRETATION FEASIBILITY

Two possible approaches were considered for identifying specific element activities executed using a crane (step 2 in figure 1). The first is to assemble a broad set of knowledge rules with if-then format, and then process any given reading through an inference engine. The drawbacks of this approach are that each activity reading must be processed in a single computation, and the rule-base is difficult to elicit and maintain.

The second approach, adopted and developed in this work, consists of the following steps:
1. Establish a standard set of characteristics that can describe any given crane activity.
2. For each possible element specific basic activity, set the range of values that can conceivably occur for each characteristic. This forms a ‘filter’ of possible characteristic values for each activity type.
3. Process each reading by comparing its individual set of characteristic values with each filter. If the reading matches the filter, then the activity performed is of the type associated with the filter.

This approach offers a number of advantages. Each reading can be preprocessed and characterized in a standard format in real-time, thus reducing data storage requirements. The filter values are relatively easy to set. It also allows for rigorous validation: all that is required in order to demonstrate the feasibility of using the system to distinguish between crane activities is to prove that one and only one filter can match any given individual crane cycle reading. For this to be the case, any given pair of activity filters must have at least one distinguishing characteristic. In other words, a sufficient condition for proving uniqueness of any two activity filters is to show that the value ranges for at least one characteristic are mutually exclusive.

4.1 Crane activity characteristics

Five independent characteristics of crane cycles (or sub-cycles), that could be determined algorithmically from the raw data, were identified for use in matching crane cycles to specific element basic activities. They are:
1. The relative locations of the loading and unloading stations. The four possible values are from outside the building into the building, from inside to outside, from outside...
to another point outside, and from inside to inside.

2. The **location of the loading station**. The possible values are the loading work envelopes set for the project. The list can be updated at any time.

3. The **location(s) of the load release station(s)** within a cycle. The data collected in the field study show that for some activities the load is not released in one single action. Observation of the same activities reveals that these are activities such as concrete pouring and placement of precast elements (precast elements are commonly set in place but not released from the crane until they have been set in place by the erection crew).

4. The magnitude of the **weight released at each release station**. The possible values are the set of distinct weight ranges appropriate for each activity type.

5. The **weight on the hook during motion after the last release point in the cycle**. If non-zero, this represents the weight of auxiliary lifting equipment attached to the hook during the cycle. The possible values are the distinct weights of each piece of auxiliary equipment, which are calibrated for the system at the start of the project.

### 4.2 Element Basic Activity Envelopes

The location value of characteristic #3 for each reading is replaced with the unique identifier (ID) of a specific element-basic activity work envelope (an EBA envelope). The full set of work envelope IDs for the building is the range of possible values for this characteristic. The volumes of the EBA envelopes are pre-calculated for each element in a building using the knowledge base and the building project model. Figure 3 shows an example of an EBA envelope for stripping the steel formwork from a reinforced concrete wall.

In some cases, the crane is used for activities that cannot be directly related to any work envelope. For these, characteristic #3 is null. In the present work, a generic material delivery activity filter was defined for these cases. In other cases, the release location may fall in more than one EBA envelope (where envelopes overlap). Hypothetically, if one considers the full set of EBA envelopes for a building, there could be many such overlapping envelopes. However, in reality, the size of the set of EBA envelopes that form the range of values for any particular data reading can be greatly reduced by considering the status of the activities with which each is associated. At any given point in time as construction progresses, a limited number of element basic activities can be candidates for execution. The candidate EBA envelope set is therefore recalculated in accordance with the logic of the technological dependencies between activities, as reflected in the construction schedule.

![In Horizontal Plane (X, Y)](image1)

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<tr>
<th>In Horizontal Plane (X, Y)</th>
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![In Vertical Plane (Y, Z)](image2)

<table>
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<th>In Vertical Plane (Y, Z)</th>
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**Figure 3. Typical crane hook location envelope for stripping formwork from a concrete wall.**

Any remaining overlap between EBA envelopes within the same execution phase implies that the system will not be able to distinguish between the associated activities based on this characteristic.
alone. In these cases, the necessary condition for establishing feasibility is that there must be a pair of mutually exclusive filters for at least one other characteristic (#1, #2, #4, or #5), i.e. other than the EBA envelope ID (which is derived from characteristic #3).

4.3 Feasibility for the Field Study Building

In the case of the building used in the field study, 25 distinct element basic activity types were identified (numbered #1 to #25 in Table 1). Comparison of the characteristic value filters without consideration of the EBA envelope ID yielded unique identification for only five of the element basic activities. Thus use of the envelopes is crucial for interpretation of the data.

When all EBA envelopes were considered, only 3 of the activity types had envelopes that occupied unique volumes in space (i.e. no overlap with any other envelope). Applying the logic of the construction phase sequence increased the number of unique envelopes to 14 of the 25, with eight distinct instances of overlap among the 11 remaining envelopes. For each instance of overlap, the mutually exclusive filter values test was applied, and brought the number of identifiable element activities to 18. Only two groups of activities remained indistinguishable from one another; a) steel-fixing (#3 in Table 1), installation of opening frames (#7) and formwork for interior walls (#10), and b) bundled rebar deliveries (#22-24) and miscellaneous material deliveries (#25). The first set can be dealt with by unifying the activities into a single ‘interior wall preparation’ activity, which can be uniquely identified. This reduces the level of detail at which interior wall activity can be reported, but it is still effective for determining the status of the higher-level construction activities (e.g. ‘build interior walls’). The second set can be dealt with similarly (united into one generic ‘miscellaneous materials delivery’ activity), although in fact it does not contribute to determining the status of the higher-level activities.

If the second set is ignored, the final result is that 19 typical element basic activities can be isolated. For each floor of the field study building, there are numerous elements of each type. When the full complement of individual element specific activities is considered, fully 353 out of a total of the original 378 (93%) can be uniquely identified.

5. PROJECT CONTROL INFORMATION

The field study results also shed light on the nature of the benefits that could be obtained from an operational system. The success of managers at both the project and company management levels in effectively controlling construction projects is dependent on information. Given appropriate software, the information that can be produced inexpensively and in real-time by the proposed system (possibly in conjunction with other measurement technologies) includes:

- Project activity progress reports – construction activity start and finish times,
- Materials consumption data (such as concrete quantities delivered),
- Net equipment hours per activity,
- Equipment usage patterns.

6. CONCLUSIONS

Analysis of the typical activities in the field study suggests that the raw data can be interpreted to produce reliable information about the timing, duration and material consumption of project activities. Interpretation is not feasible without use of the element basic activity work envelopes to distinguish between crane cycles which have otherwise overlapping set so characteristic values. Furthermore, reduction of the set of envelopes to include only those associated with basic activities that are candidates for execution at any point in time is crucial for success of the system. In the case of the field study building, once the range of potential overlaps was reduced, the test for mutually exclusive characteristic filters revealed that 93% of the activities could be uniquely identified; the remaining 7% were of a type that was unnecessary in determining the status of the higher-level construction activities.

Monitoring lifting equipment such as tower cranes therefore holds the potential to provide reliable, cheap and machine-readable information describing project progress, durations for basic construction activities at the level of individual building elements, and relatively precise consumption quantities for certain materials (such as concrete or rebar cages).

The next stage in this research is to implement the system and apply it to one or more projects for durations longer than was possible in the field study. This includes developing a standard set of EBA envelope definitions and implementing
software routines to interpret the data. For each project, a 3D project model and a construction schedule must either be supplied or purpose-built. The goal would be to demonstrate a system that could automatically update the project schedule, report activity durations for calculating resource consumption rates, and report material consumption quantities.

7. REFERENCES


Table 1. Basic Activities and Building Elements (element specific activities are numbered #1 to #25).

<table>
<thead>
<tr>
<th>Activities</th>
<th>Fix reinforcing steel cages</th>
<th>Set door/ window opening frames</th>
<th>Build formwork</th>
<th>Pour concrete</th>
<th>Strip formwork</th>
<th>Install hollow-core planks</th>
<th>Deliver rebar in bundles</th>
<th>Other</th>
</tr>
</thead>
<tbody>
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<td>Perimeter columns</td>
<td>#1</td>
<td>-</td>
<td>#9</td>
<td>#11</td>
<td>#19</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Perimeter beams</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
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<td>#7</td>
<td>#10</td>
<td>#12</td>
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<td>-</td>
<td>a</td>
<td>#14</td>
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<td>-</td>
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<tr>
<td>Floor sections</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>#15</td>
<td>-</td>
<td>a</td>
<td>#21</td>
</tr>
<tr>
<td>Core walls</td>
<td>#6</td>
<td>#8</td>
<td>-</td>
<td>b</td>
<td>#16</td>
<td>-</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>Core slab sections</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>#17</td>
<td>-</td>
<td>a</td>
<td>-</td>
</tr>
<tr>
<td>Stairs (core)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>a</td>
<td>#18</td>
<td>-</td>
<td>a</td>
<td>-</td>
</tr>
</tbody>
</table>

a: These activities were performed using conventional formwork without the crane.
b: These activities were performed using a set of self-propelled climbing forms.
Intelligent Agent-based Subcontracting System in Construction

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ABSTRACT: Practically, the effective management of subcontracting selection within a construction project has been regarded as one of the critical factors for achieving project success. This study takes advantage of IT initiatives of e-commerce to combine with the use of electronic information exchange standards Java XML (extensible markup language) to propose a “push-strategic” and agent-based online subcontract bidding and negotiation architecture. The design of agent will make it possible to automatically sense the changes in its environment and react accordingly on behalf of the host. The information agent deals with all manipulation of incoming and outgoing messages following the pre-defined communication mechanism. Furthermore, it will communicate with other information agents mounted on all other contract nodes, and also with its local decision support system through the mapping rules. The ultimate goal of this study is to build an agent-based automatic subcontracting environment for Multi-Agent System (MAS) to achieve the effective communication and optimization within the process of subcontractor selection. A proto information system has been designed and implemented in the study. The proposed agent-based subcontracting system, after being made into a widespread and workable process in the future, could expectably become a new paradigm for the subcontracting procurement of the construction industry.

KEYWORDS: E-Commerce, Intelligent Agent, Subcontract, XML

1. INTRODUCTION

Due to the specialized technological divisions of labor in the construction industry, a large majority of engineering functions and values of a project are carried out by specialized engineering firms coordinated and controlled by the master contractor. Traditionally, the practice for selecting subcontractors was to take the way of choosing while working on the project, especially those who were set to work together with or those with whom one had already done business, which gave rise to quasi-firm sub-structures. Nevertheless, because of factors related to limitations on finance, manpower, time, and information in traditional procurement, there is often no way to effectively expend the sample space to try out new clients, which can give rise to inefficiency in subcontractor selection and negotiation processes. However, in recent years, the rise of the Internet and e-commerce has thoroughly changed the traditional market's business rules and has brought a revolution in transaction practices. The use of Internet-based technology initiatives makes the exchange of information simple, fast, omnipresent, and accurate, and brings a new, pivotal opportunity and force to the enhancement of the subcontracting supply chain management. Starting from and looking toward Internet, the subcontractor selection can be categorized as B2B e-procurement in this age of digital commerce. Meanwhile, the present e-procurement is mainly focused on the “pulling strategy.” That is, the master contractors who call for subcontracting tenders may establish and maintain a homepage within the specific web-server to post the bidding information and then passively wait for tendering. The pulling way of e-procurement has certainly improved the past flaws of selection from limited candidates, but somehow it is apparently too passive to customer-oriented in tendering process. Recently, agent-based electronic commerce has become even
more widespread as agent and Web technology become more powerful and flexible. Therefore, beyond considering the pull way of e-commerce, the “push strategy” implemented by agent-based subcontracting system is proposed to strengthen the ability of customer-oriented e-procurement and create an automatic mechanism of data acquisition. The push-strategy agent will automatically and precisely transfer tendering information to the specific potential subcontractors, and thereafter deal properly with all relevant responses from them through the Internet. In this research, the overall subcontracting supply chain of a construction project is considered as a global procurement system and an intelligent agent-based subcontracting (ABS) system is developed to obtain optimal combination of subcontractors selection. ABS is programmed to make decisions based on the decision-maker’s personal preferences. Combined use of XML (extensible markup language) and Java language allows ABS and other automated processes to access and interact with Web-based information more easily. In the proto-model, ABS shows the ability to facilitate communication, collaboration and coordination, brings more analytical power to bear in the development of solution, and reduces the amount of human intervention in organizational processes. As a matter of fact, the development of ABS is a preliminary trial to take the subcontracting and purchasing process into intelligent re-engineering through omnipresent Internet.

2. INTELLIGENT AGENT

There has been much discussion about whether a certain system is an agent or merely a program. This research does not intend to manifest the historical problem of defining these terms in artificial intelligence. However, intelligent agents could be more easily distinguished from a program due to three major features: autonomy, cooperation, and learning. Nwana defines an agent in terms of the three behavioral attributes, any two of which must be possessed by an intelligent agent [1]. (1) Autonomy: Intelligent agents can operate on their own without the need for human guidance. Therefore, they have individual internal states and goals, and act to meet their goals on behalf of their users. (2) Cooperation: Since agents are designed to act on behalf of their hosts, they would cooperate with other agents or humans. In order to cooperate, agents need to possess a social ability, i.e. the ability to interact with other agents and possibly humans via some communication language. (3) Learning: For agents to be truly regarded as intelligent, they would have to learn as they interact with their external environment since the learning ability has almost been regarded as one element of intelligence. This research adopts Nwana’s suggestion to define an intelligent agents: “A program is an intelligent agent if it possess any two of behavioral attributes: autonomy, cooperation, and learning”[1,2,3,4].

Intelligent agent research grew out of Distributed Artificial Intelligence (DAI). The aim of this area was to gain the benefits of modularity when tackling large, real-world problems. With the advent of the wide usage of the Internet, new and somewhat more manageable research areas started to open up, as the Internet is essentially an ideal electronic environment for agents. In the last few years, there has been an explosion in the amount of information available on a daily basis. This information may be stored as passive stored databases and files or it may be information we need to actively request in order to make a decision. Much of this information is stored remotely in a variety of formats and sources; much of it badly labeled, and much of it time-consuming to locate. This has led to a state of affairs where traditional IT systems are increasingly hard-pressed to meet many information gathering challenges. Whereas, previously, humans would take on the role of sifting and coordinating gathered information in order to take decisions, agent-based software technology is rapidly evolving to perform all of these functions. Agents are considered particularly useful for tackling large-scale, real-world problems involving multi-disciplinary perspectives. They are currently applied to a variety of application domains including workflow management, telecommunications network management, air traffic control, business process re-engineering, information retrieval and management, electronic commerce, personal digital assistants, e-mail filtering, command and control, smart databases and so on. [1,5,6,8].

3. APPROACH

Due to the potential for a high number of subcontractors on the market, every business usually employs a certain kind of software system to manage and record documents and information. The formats and standards of each system are possibly different, and without format conversion, it is not easy to share and exchange documents and information. Because of this, an agent-based communication environment for subcontracting is
developed to achieve this goal to conquer the difficulty of problems related to different information system platforms and software compatibility as well as problems related to encryption of data heterogeneity.

Since there has long been a consensus in the industry that a standard ontology is required for efficient data exchange, in this research we follow aecXML’s framework developed by World Wide Web Consortium (W3C) for data schema, and define all possible categories of subcontracting information using its terminology, and developed the data structure of XML Schema for Project Subcontracting (SPS) by modifying the aecXML framework. Meanwhile, the Data Acquisition Language for Subcontracting (DALS) is also developed using the syntax of eXtensible Stylesheet Language Transformation (XSLT) as the media for requesting standardized subcontracting information as well as the associated responses. Message Agent is endowed with SPS and DALS, and thus able to autonomously deal with all messaging tasks. Each potential subcontractor equips a Message Agent as a unique information window to automatically acquire external information and also provide relevant responses. While the master contractor receiving responses from subcontractors, the selection process will succeed to be run in the decision support system of general contractor according to the decision-making mechanism of optimal selection. The complete mechanism is some complex to discuss here, and details can be referred to Lin (2001)[7].

Figure 1. Architecture of Message Agent

This research assumes that all the subcontracting suppliers are equipped with a Message Agent developed by Java language. Figure 1 shows the Message Agent is composed of four major processors: Requester, Responser, Interpreter, and Dispatcher. Requester and Responser check the message Queue regularly, and retrieve the requests and responses, respectively, which are then further processed. Interpreter identifies the request and decides the procedure of request manipulation. Dispatcher dispatches the requests from Interpreter or Requester and the responses from Responser to the next destination. While generating or altering the messages, all processors either check the syntax and data structure of the incoming messages or follow the data schema according to ontology base. Figure 2 is an illustration and the schematic representation of the operation of this ABS system. The general contractor pushes specific tendering information constituted by pre-defined XML formats to the potential subcontractors (A, B, C, …, X). Each project member in this project equips a Message Agent that continuously and regularly monitors its Message Queue and performs proper message manipulation.

4. SYSTEM IMPLEMENTATION

The developing environment of the implementation of the present system is a visual programming tool for Java called JBuilder 6.0 Personal, Borland Software Corporation. With an integrated, extensible source code editor, graphical debugger, compiler, visual designers, timesaving wizards, sample applications, tutorials, multimedia training, and support for Java standards, JBuilder Personal 6 makes learning and using Java easy. Table 1 and 2 show the details. Message Agent was implemented using Java 2 and tested in IBM PC with Windows 2000 OS. Figure 3 shows the configuration board upon booting Message Agent. The configuration such as folders, Host Name, and Host URL, is set up here at the first time of running. By clicking the button “Save” on the board, the configuration is saved for the following use by Message Agent. The content of XML document is cited an instance as Figure 4.

The linkages between the Message Agent and local DALS-speaking DSSs are DALS and the file folders where the DSSs put their requests in and the Message Agent accesses these requests and dispatches them. Figure 5 (a) and (b) illustrates the relationship between them. In Figure 5 (a), DALS-speaking DSSs generate DALS-based requests and deposit them in “Outbox Request Queue”, which is regularly checked and dispatched by the Message Agent. The corresponding
responses to original requests are then received by the Message Agent for a certain while later, and are deposited in “Inbox Response Queue”, which is checked and accessed by DALS-speaking DSSs. On the other hand, as shown in Figure 5 (b), the Message Agent passes the incoming requests from other MAs and deposits these request in “Inbox Request Queue”, which is regularly checked and processed by specific DALS-speaking DSSs. Responses corresponding to those requests are then generated and deposited in “Outbox Response Queue” by DSSs, which is regularly checked and dispatched by the Message Agent. This cycle of interoperation between Message Agent and DALS-speaking DSSs is beyond the scope of this paper due to the high complexity degree of communication between two software applications. A complete functionality of an automatic communication system should include this cycle.

Table 1. System implementation and developing tools

<table>
<thead>
<tr>
<th>Language</th>
<th>Java</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing Tools</td>
<td>Jbuilder</td>
</tr>
<tr>
<td>Operating System</td>
<td>Win 2000 or compatible</td>
</tr>
<tr>
<td>XML Parser</td>
<td>Xerces 2</td>
</tr>
<tr>
<td>XSL Processor</td>
<td>Xalan 2.0</td>
</tr>
</tbody>
</table>

Table 2. Contents of Java packages adopted by this study

<table>
<thead>
<tr>
<th>Java Package</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>org.w3c.dom</td>
<td>DOM Level 2 classes and interfaces</td>
</tr>
<tr>
<td>org.xml.sax</td>
<td>SAX 2.0 classes and interfaces</td>
</tr>
<tr>
<td>javax.xml.parser</td>
<td>JAXP interfaces</td>
</tr>
<tr>
<td>javax.xml.transform</td>
<td></td>
</tr>
<tr>
<td>SAXParserFactory</td>
<td>Used in all DOM applications to obtain a Document object (DOM tree)</td>
</tr>
<tr>
<td>TransformerFactory</td>
<td>Used in all XSLT applications to obtain a Transformer object</td>
</tr>
<tr>
<td>org.apache.crims</td>
<td>Reference implementation classes for the XML parser</td>
</tr>
<tr>
<td>org.apache.xerces</td>
<td>Reference implementation classes for the XML parser (adopted in this research)</td>
</tr>
</tbody>
</table>

5. PROGRAMMING FEATURES

Instead of description of details of the design of objects formulated by Message Agent, several programming features are addressed here, which are multi-thread processing, parsing with a validating mode using XML Schema, and the use of Remote Method Invocation (RMI).

(1) Multi-thread processing: Multiple threads mean that there are more than one single thread running at the same time and performing different tasks within a program. Not every programming language supports the mechanism of multiple threads. Java not only supports multiple threads but also provides with many utilities including of setting thread priority, synchronizing threads, and grouping threads to manage all threads within a program. Since carrying out various manipulations of a message, the Message Agent is implemented with multiple threads and thus different manipulations of a message are able to proceed independently and smoothly.

(2) Validating a XML document using XML Schema: A DTD defines the data structure of an XML document. It specifies the order in which tags occur, what the tags are, and how many tags are allowed. A DTD provides a uniform format for defining the structure and markup of an XML document. Unlike DTDs, however, XML Schemas adhere to the XML specification and provide better support for XML namespaces and more data types. It is also a recommendation of the W3C. Schemas provide a more flexible means for defining the
structure, content, and semantics of XML than DTDs. In many areas of application, DTD is replaced with XML Schema nowadays although DTDs had been widely adopted for years. Due to the above-mentioned advantages of XML Schemas, the Message Agent adopts a validating parser using XML Schema.

(3) Use of Remote Method Invocation (RMI): Since several major manipulations of a message are involved in passing an XML-based message from a local Message Agent to remote Message Agents, an approach of file transferring from one host to another is required by the Message Agent. Although the protocol File Transfer Protocol is an easy way to be applied to this end, the Message Agent adopts a special remote access mechanism provided by Java called Java Remote Method Invocation (RMI). RMI mechanism is used by the Message Agent to pass an XML-based message from a local host to other remote hosts using specified Uniform Resource Indicators (URIs). RMI system allows an object running in one Java Virtual Machine (VM) to invoke methods on an object running in another Java VM. RMI provides for remote communication between programs written in the Java programming language.

Although the ABS system has so far not been evaluated by the industry, yet there are simple virtual scenarios tested by the authors to validate the feasibility of the whole agent system based on the push-strategy of e-commerce. And ABS shows a performance with positive results from those workable tests.

6. CONCLUSIONS

Amidst rising trends of corporate specialization, the ability to properly manage subcontracting procurement is a key factor in maintaining competitiveness. This research has demonstrated a theoretically practical framework to select the optimally combinatorial team of subcontractors, and brings an all new vision to the development of electronic procurement system in digital economy. Following the macro viewpoint of systematization and standardization, businesses can integrate with their own Enterprise Resource Planning (ERP) system to gain further benefits from their resources, and take a step toward platform systematization for different organizations and work units to meet their ultimately long-term goals.

Accordingly, this research takes advantage of IT initiatives of e-commerce to combine with the use of electronic information exchange standards Java XML to propose an agent-based online subcontract bidding and negotiation architecture. The design of software agent has made it possible to automatically sense the changes in its environment and react accordingly on behalf of the host. The information agent deals with all manipulation of incoming and outgoing messages following the pre-defined communication mechanism. Further, it will communicate with other information agents mounted on all other contract nodes, and also with its local decision support system through the mapping rules. The proposed agent-based subcontracting system based on the active push-strategy of e-commerce, after being made into a widespread and workable process in the future, could expectably become a new paradigm for the subcontracting e-procurement of the construction industry.

7. ACKNOWLEDGEMENTS

The authors would like to acknowledge the National Science Council, Taiwan, for financially supporting this work under contract No. NSC-91-.

8. REFERENCES


Figure 2. Schematic representation of the system  

Figure 3. The configuration board of Message Agent

```xml
<Header>
  <Request requestId="msg101010" date="2001-01-01">
    <Sender role="GC" url="ftp://140.112.10.16/gc">Continental Company</Sender>
    <Receiver role="SC" url="ftp://140.112.10.78/sc1">Smart Excavator</Receiver>
  </Request>
  <Response responseId="msg101010" date="2001-01-02">
    <Sender role="SC" url="ftp://140.112.10.78/sc1">Smart Excavator</Sender>
    <Receiver role="GC" url="ftp://140.112.10.16/gc">Continental Company</Receiver>
  </Response>
</Header>
```

Figure 4. An XML instance for a response/request

Figure 5. Interoperation between Message Agent and DALS-speaking DSSs
An Integrated Methodology for Construction BPR and ERP by using ARIS and UML Tool

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ABSTRACT: In order to improve the efficiency of construction management, a new methodology—Beauty is presented to develop translatability for construction BPR (Business Process Reengineering) and ERP (Enterprise Resource Planning) by using ARIS (Architecture of integrated Information Systems) and UML (Unified Modeling Language) tool. The Beauty method includes four phases that inclusive of business process modeling, business process reengineering, function mapping and system planning. Using Beauty method, inefficient operations within an enterprise working process can not only be identified, but also a new rational operation process can also be developed to improve efficiency. Besides, the competitive ability of a construction company is also increased. The major contribution of the Beauty method is to understand and confirm what is needed and correct process in the enterprise before running the construction ERP system. The research possibilities are identified and tested based on the implementation of the Beauty method. To some extent, this research also establishes a new agenda of process reengineering for future research.

KEYWORDS: Enterprise Resource Planning (ERP); Business Process Reengineering (BPR); ARIS; Unified Modeling Language (UML)

1. INTRODUCTION

Research Motive

The concept of ERP be presented that can integrate enterprise systems recently. According to Matti Hannus mention the concept that “Islands of Automation in Construction” [1]. The following figure 1 describes the automation in construction industry. Because of multi-roles joining and working in different projects will lead to the problem of information integration between projects in construction enterprise.

![Figure 1. Islands of Automation in Construction [1]](image)

In the past, enterprise at large implement information technology (IT) systems usually focus on single department or organization. All kinds of information systems in enterprise will come apart each other. Each information system likes an island. However, all of the information islands become independent respectively. When each department implements individual information system, each department will become individual information island. This situation will lead information flows, working flows and other flows to run between departments not smoothly. It will cause barrier and hurdle to integrate these flows each other. How to integrate flows between departments is becoming a new planning aspect by ERP system planners. Besides, according to investigation of Marina Krumbholz and Neil Maiden’s research (2001) point out some problems of enterprise implements ERP system in the past [2]. Averagely, the cost increased more than 1.78 times, and the time wasted more than 1.5 times of enterprise’s anticipation when implementation period. Another investigation points out the cases of enterprise implementation ERP system had 96.4% failure in the past [3]. The most serious situation leaded enterprise to close down.

Productivity in construction industry is project-based. When general contractor wants to implement ERP system. We must consider the productive pattern from project-based sites in contractor. This is a characteristic in construction industry. We want to make the implementation ERP system and business process more match and enhance the performance of ERP system. In ERP implementation process, there is a big problem existing for a long time. It is that enterprise employees know about how business processes operated in enterprise, but they don't know how to develop system planning;
other words, ERP system planners know about how system planning developed, but they don’t know about business processes in their customers (enterprises). Therefore, when both roles cooperate to implement ERP system in enterprise will not make enterprise processes and system planning more match. This research will try to solve this big problem to avoid implementing ERP system failure. Because of enterprise implementation ERP system is time-wasted and cost-expensively that we expect to implement it in enterprise more successfully.

Research Objective

This research is focus on how to implement ERP system in construction industry and how to construct a transformation method between business processes and ERP system. It can become a consideration method when enterprise will implement ERP system. The following figure 2 illustrates the research objective.

![Figure 2. Honeycomb structure diagram of research objective](image)

Research Limitation and Scope

This research is based on business process reengineering (BPR) and enterprise resource planning (ERP). This research methodology named “a integrated methodology for BPR and ERP by using ARIS and UML to construct Translatability, Beauty methodology”. In figure 3, a whole procedure of implementation ERP system will include “BPR”, “Integration” and “build up ERP system” three parts. Because of page limitation, the “build up ERP system” part won’t illustrate. So we use duck color to show in figure 3. We just can illustrate “BPR” and “Integration” two parts in this paper.

2. PROBLEM STATEMENT

Via the above mention about feature of construction industry, the most important purpose in this research is that how to improve information advancement in construction enterprise by implementing ERP system. In table 1, we compile problem definition, description and solution of information apart in construction industry. Combining BPR and ERP regards as a total solution of enterprise information apart. In sum, BPR and ERP are concepts; Build up ERP system is a practice. In table 1, it classifies about the concepts of ERP and the practices of ERP. The following is classified:

1. Regarding the concept of ERP.
   (1) Confirm goals of enterprise.
   (2) Analyze and define needs of enterprise.
   (3) Evaluate main business processes.
   (4) Analyze original business processes.
   (5) Design better business processes.

2. Regarding the practice of ERP.
   (1) Match business processes with ERP system modules.
   (2) Develop system implementation planning.
   (3) Start to system planning.

![Figure 3. Research scope diagram](image)
Via the above mention about the concept of ERP and the practice of ERP, we can comprehend and find out the problem solutions below:
2. Business processes and system planning integration.

3. ERP IMPLEMENTATION METHODOLOGY

Structure of Beauty Methodology

In Beauty method, it will use ARIS and UML two modeling tools. The most important is that how to translate business processes to system planning. In figure 4, the left dotted block includes BPM and BPR phases. These two phases will mainly use ARIS tool to proceed to business process discussion. The middle dotted block includes function-mapping phase. The phase will mainly develop the translatability between business process and system planning. The right dotted block includes system-planning phase. The phase will mainly use UML tool to proceed to system planning. A c t u a l l y , t h e function-mapping is the kernel part in Beauty method because it build up the translatability. In the other words, Beauty method is like a bridge between business processes and ERP system planning.

4. CASE STUDY OF CONSTRUCTION INDUSTRY

Business Process Modeling (BPM)

There are four steps in this phase, include defining business process modeling scope, data collection, identifying main business processes and proceeding to business process modeling. The first step is that defining business process modeling scope. We must understand expectation of enterprise when deciding to implement ERP system. Let us know what functions of enterprise will need to redevelop. Production, marketing, human resource, R/D and financial function will be involved in process modeling scope. The second step is that data collection. After redeveloping enterprise functions, data collection must be involved all related information, like standard operating procedure (SOP), operating documents, operating tables and history cases in enterprise (table 2).

<table>
<thead>
<tr>
<th>Table 1. Problem definition, description and solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem</strong></td>
</tr>
<tr>
<td>Information Aspect</td>
</tr>
<tr>
<td>Regarding the concept of ERP</td>
</tr>
<tr>
<td>Regarding the practice of ERP</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 1. Problem definition, description and solution

Figure 4. Structure of Beauty methodology
When data collection step gets ready, we can enter the third step that identifying main business processes. We must confirm main processes of enterprise. In this step, we use VAD diagram of ARIS tool to express main processes in enterprise (Fig 5). It is initial process showing in ARIS tool. When VAD diagram is finished, we can enter the fourth step that proceeding to business process modeling. First, we develop process investigation table to know start activity, end activity, term activity, activity explanation, each activity related staffs, each activity input data and output data (Table 3). Second, we develop eEPC diagram to show investigation business process on the other way. It is a detail process showing in ARIS tool. In fig 6, first activity finished and passes on to second activity. There are what staffs related, what data be used by staffs and how the second activity be succeeded to the output event. eEPC diagram let us know about what staffs, activities, datum and events will be related in business process clearly.

### Table 2. Data collection for payment/bill process

<table>
<thead>
<tr>
<th>Department</th>
<th>Code</th>
<th>Manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering dept</td>
<td>Engineer</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Process:</td>
<td>Project payment and bill process</td>
<td></td>
</tr>
<tr>
<td>Explanation:</td>
<td>When project has finished in a milestone, subcontractor had to ask for project engineer to charge regularly.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative Information</th>
<th>Have</th>
<th>Haven’t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise Department Structure Diagram</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Standard Operating Procedure</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Project Planning Report</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Main processes by VAD diagram

Business Process Reengineering (BPR)

There are four steps in this phase, include confirming business process modeling (As is), checking business process streamline, checking business process reengineering rules and business process reengineering (To be). The first step is that confirming business process modeling (As is), when we finished business process modeling phase above paragraph. We must discuss with related staffs to confirm the correctness of process investigation table and eEPC diagram. The second step is that checking business process streamline, we will focus on checking the rationality of streamline. We develop five cases of process streamline styles (Table 4). Table 5 is that explanation of five cases. For example, if process streamline strike across many departments or staffs. Maybe it means that some departments or staffs aren’t necessary to be strike across. So we have to reduce unnecessary departments or staffs to make process streamline more simplify. Besides, we must check rules of business process reengineering to eliminate unreasonable activities in process. The third step is that checking business process reengineering rules which include to refer to combination similarly activities, reducing unnecessary examine or supervise works, learning from other successful enterprise business process and automation of some activities in business process to reduce human effects. When we finished from the first to the third phases, we can make business process reengineering (To be).

### Table 3: Payment/bill process investigation table

<table>
<thead>
<tr>
<th>Started staff at first activity: Cost control staff</th>
<th>Input data</th>
<th>Output data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check amount of bill</td>
<td>Check the amount of bill from contractor or subcontractor</td>
<td>The amount of number and money of tables</td>
</tr>
<tr>
<td>Fill up evaluation tables</td>
<td>According to output data above, fill up evaluation tables</td>
<td>Evaluation tables</td>
</tr>
<tr>
<td>First time to verify evaluation tables</td>
<td>Project manager will verify evaluation tables</td>
<td>The first time Verified evaluation tables</td>
</tr>
<tr>
<td>Second time to verify evaluation tables</td>
<td>Engineering director will verify evaluation tables</td>
<td>The second time Verified evaluation tables</td>
</tr>
</tbody>
</table>

Figure 6. Bill process eEPC diagram
Redevelop original business process to become new business process. Absolutely, there are new process investigation tables, eEPC diagrams and business process streamlines will be developed.

Table 4. Five cases of process streamline

<table>
<thead>
<tr>
<th>Activity</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity A</td>
<td>(same)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
</tr>
<tr>
<td>Activity B</td>
<td>(same)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
</tr>
<tr>
<td>Activity C</td>
<td>(same)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
</tr>
<tr>
<td>Activity D</td>
<td>(same)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
</tr>
<tr>
<td>Activity E</td>
<td>(same)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
<td>(two)</td>
</tr>
</tbody>
</table>

Table 5. Explanation of five cases

<table>
<thead>
<tr>
<th>Cases Type</th>
<th>How to modify?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>This streamline is running in the same dep. /staff. It's well streamline, doesn't need.</td>
</tr>
<tr>
<td>Case 2</td>
<td>This streamline is striking across two dep. /staff or upward. Reducing unnecessary dep. /staff.</td>
</tr>
<tr>
<td>Case 3</td>
<td>This streamline is striking across two dep. /staff or upward. And it comes back same dep. /staff replicated. Reducing unnecessary dep. /staff and avoiding some activities replicated.</td>
</tr>
<tr>
<td>Case 4</td>
<td>This streamline is striking across two dep. /staff or upward. And it comes back some activities replicated. Reducing unnecessary dep. /staff and avoiding some activities replicated.</td>
</tr>
<tr>
<td>Case 5</td>
<td>This streamline is striking across two dep. /staff or upward. And it comes back some activities replicated. Reducing unnecessary dep. /staff and avoiding some activities replicated.</td>
</tr>
</tbody>
</table>

Function Mapping

There are six steps in this phase, include confirming business process reengineering (To be), developing process function table, drawing process function diagram, building up system planning criteria table, acquiring system planning components and making components category table. The first step is that confirming business process reengineering (To be). We inherit from the result of BPR phase. We must discuss with related staffs to confirm the correctness of new process investigation tables, eEPC diagrams and business process streamlines. The second step is that developing process function table. We classify the result of BPR phase to become “event”, “function”, “organization” and “data” four categories according to investigation table, eEPC diagram and process streamline (Table 6).

When we develop process function table at the ready. The third step is that drawing process function diagram. We draw function, data, event and organization four diagrams according to process function table. For example, fig 7 and fig 8 are function and data models.

![Function model from process function table](image1)

Fig 7: Function model from process function table

![Data model from process function table](image2)

Figure 8: Data model from process function table

The fourth step is that building up system planning criteria table. We transform process function table, event model, function model, organization model and data model into system planning criteria table. This step is critical point that transforms business process (using ARIS tool) into ERP system planning (using UML tool). In the other words, we can say it is important referring to system planning successfully. The fifth step is that acquiring system planning components. We try to acquire useful components from the results of the second to the fourth steps before UML system planning. After acquisition, we can make components category table at the sixth step to prepare for system planning phase (Table 7).

Table 6. Process function table

<table>
<thead>
<tr>
<th>Process function table</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Name</td>
<td>Department or staff</td>
</tr>
<tr>
<td>Use-Case</td>
<td>Process name, event, entity or information</td>
</tr>
<tr>
<td>Class Number</td>
<td>Department's name, staff or entity</td>
</tr>
<tr>
<td>Attribute</td>
<td>Attribute (eg. Subcontractor’s name, evaluation table’s name etc.)</td>
</tr>
<tr>
<td>Operation</td>
<td>Attribute (eg. The motion of verify, the motion of calculate etc.)</td>
</tr>
<tr>
<td>Message</td>
<td>Information (eg. Subcontractor finished a part of project etc.)</td>
</tr>
</tbody>
</table>

Table 7. Components category table
5. CONCLUSION

Enterprise implements ERP system almost failure as a result of existing a gap between enterprise employees and ERP system planners. The gap is that they don’t understand the other side affairs each other. Beauty method tried to solve this problem. Enterprise applies Beauty method before ERP system implementation will make business processes into system planning. The result will be taken for the specification by ERP system planning company. In sum, we build up the four phases and hope to help enterprise implement ERP system more successfully.
6. REFERENCE


Practitioners Report on Applied Industrial, Flexible and Sustainable Building in the Retail and Office Sector

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ABSTRACT: Building projects which are build in the Dutch Industrial, Flexible and Sustainable (IFD) Building programme usually focus on the design of the project and the application of prefabricated parts. Though this is indeed an important factor in IFD-projects, the paper supports the idea that successful IFD projects rely on three aspects: An industrialised product, an industrialised building and supporting ICT process and the accompanying organisation structure based on industrial paradigms. For the realisation of the ‘Runshopping Centres (RSC)’ we build in The Netherlands we organise our projects far more innovative than us current practise. We build without a construction company. By contracting the various systems in the buildings to partnering suppliers -who often are shareholders in the project- on a performance contract basis, we create far more durable solutions than normal in this industry and create high quality buildings.

Key to our success is the building system we developed. This ‘LEGO’-like building system allows us to be very flexible in the design and construction phase of the projects and promise even re-utilisation of building materials. Our physical building system is closely matched by the ICT and CAD systems we use. For this to succeed it is necessary to use an integrated design and configuration management system around the entire project. This paper describes how this is done.

KEYWORDS: Industrial Building, Configuration Management, Comakership, Sustainable Building, CAD, Databases.

1. INTRODUCTION

A lot of people think that the Dutch IFD programme is about building with prefabricated parts alone. Far more important is that the sector looks at other industries and organises the way in which one collaborates and sets up the process around the project from inception until demolition. Goal of the entire exercise is to get a nuisance free product for the end-users. This product is space to do business or live in (See [Dame1997]). This paper describes the way the partners in the AKB de Boele group realise a network organisation, organises the project and control the process during its entire life cycle. Furthermore a description of the integrated database for design, planning and facility management is introduced.

2. THE PRODUCT

Core business of our group is the realisation of buildings in the retail sector. Therefore we developed a retail concept for shops in the private building and aligned business called ‘Runshopping’.

The product we deliver is space for retail in the form of large halls at the periphery of urban areas combined with office space and sometimes housing. The end user rents or buys the space per square meter and becomes a member of an association of owners of the retail centre.
We developed the product in such a way that the cost of the building is optimised for the entire life cycle. This enables us to introduce a lot of sustainable building measure like providing better insulation, use state of the art heating and cooling installation techniques, integrate glass-fibre based networks, etc. The total cost of ownership is in this way lower than for comparable buildings, although the quality of the buildings is higher and the erection costs of the buildings themselves are probably a little higher than normal. This means that we can deliver a better building for a lower price per square meter.

The structure of the buildings is mostly composed of prefabricated concrete parts. The project as depicted in Figure 1 is the Runshopping Centre RSC-Oostpoort which is currently being build near Roosendaal in The Netherlands. This project has won the Dutch IFD demonstration status. With RSC Oostpoort we are now building the 5th Runshopping Centre. RSC Oostpoort is probably the most advanced of our projects, as we are improving project by project. It is a retail area in the first phase of about 65,000 m².

For the design of the building we worked out a building systems we call internally the ‘LEGO’-like’ building system. It consists of a database filled with standardised building elements which is coupled to a CAD system. The core of the systems is in the details of the interfaces between the elements. The design and specification of the interfaces are laid down in our ‘Detail Book’ which also defines which partner is responsible for the detail in design, engineering, delivery and operation. The architect may design the building only within the constraints of the detail solutions as laid down in the ‘Detail Book’. This means using a standard grid, use of standardised building elements but little constraints in the final architecture.

3. ORGANISATION

R&D projects and specific building projects like the project Half-Time and the building of the Westerscheldetunnel have shown that contracting scheme and way in which partner collaborate are key to success in realising state of the art projects. Two levels of partnering can be determined in our organisation. The first level partners are the partners in the WAT (Working Apart Togethels) concept. These partners, being independent organisations, each performing there own role in the process work close together in acquiring new projects, organising the planning and design and managing the actual building process. This group share their premises, administration, sometimes secretariat and telephone number. They consist of an architect, project developer, real estate broker, an ICT company, a facility management company, a building system developer, building site co-ordinator and a building cost expert.

The second level of organisation is in the partners who are gathered as share holders in the company set up for a specific building project. They provide about 20% of the capital to start the project and usually consist of organisations from the supplying industry working on the project. This means that these companies build for themselves and become owner of the building they supply there products to. This is a stimulus to supply the best material and not economise on quality.

4. DESIGN AND PLANNING PROCESS

Core for controlling the process and the configuration of the project is the organisation of the information (flow). Therefore we set up a central database containing all information related to the project(s). Figure 2 depicts the core structure of the database we have set up. The database contains two groups of information containers. The first group contains generic (project independent) data like the library of building elements, a generic ‘project procedure planning’ in which all tasks from inception, acquisition of permits, erection of the buildings and park management are present.

1 LEGO stands for ‘Low threshold Element oriented Generic Organisation of the building process’. It has some conceptual similarities to the well known Danish plastic building toys in which things are stacked together with well developed interfaces. Lego also happens to be Latin for ‘I compose’ which perfectly covers the concept.
Core of the design process is a CAD system which is build upon a database concept and works entirely 3D. True configuration management can only be based on the concept bases on the product structure as a product model and not on managing a drawing structure (See [Firm2001]). Our way of working is with parameterised objects stored as elements in a library of the CAD database and which are referred to in the specific projects. For this we use the Belgium CAD system STAR (see [Star2003]). The 3D model is used in the earlier phases of the design and planning process. After the final design is ready 2D AutoCAD™ drawings are generated from the 3D model and enhanced where necessary. These drawings are necessary in the communication to other partners and for documentation.

Information exchange to partners is done via a commercial internet based document management system (File2Share™ see [F2S2003]), which by now has become the de-facto standard in The Netherlands.

Because we store both the design as the planning in the database on project level we can produce day to day planning updates in the form of scenario’s (see Figure 3.).

This scenario contains information for the suppliers about the layout of the building site, what is to be done of the specific day and which parts are required for this day. This enables us to work according to the industrial ‘Just In Time’ concept and avoids large piles of material on the construction site and unnecessary capital binding. We are currently working on an extranet site so we can publish updates to the partners on a real-time basis.

5. SUSTAINABLE CONCEPTS

Several sustainable features of the project can be mentioned. First of all the buildings can be taken apart completely where the elements can either be reused or recycled in an environmental friendly way. In the RSC Oostpoort project a special construction is developed to assemble the concrete parts using steel couplings which are bolted together (See Figure 4). In this way the re-usability is very high and also the flexibility during the life time of the building is high because changes can be made at any time without having to destroy parts of the structure.
Another aspect of the sustainability of the projects is the fact that energy efficiency and pollution prevention is optimised for the entire life of the building. In fact by applying state of the art insulation techniques in roofs and walls the energy performance of the project is spectacular. Measurements on one of the completed projects have shown that for a 40,000 m² retail centre we achieved a CO₂ reduction of 380 ton per year and a reduction in natural gas consumption of about 70%. To get these results we used insulation packets of 20 cm thick on the roofs, installed a few aquifers so excess heat in the summer is stored in the ground to be used in the winter and visa versa.

6. IMPLEMENTATION ASPECTS

For the ICT minded: The information system described in chapter 4 is implemented around a MySQL relational database system and disclosed to the local intranet using PHP4 scripts (See [Gree2001]). First setup of the database structure was done using MS-Access and some of the front-end applications in house are still using MS-Access forms and reports linked MySQL database using ODBC. We are currently working on migrating the Windows-XP based MySQL server to a Linux environment for cheaper control and possible migration to an external internet service provider.

The database contains tables about organisations, building elements, including their geometric aspects, projects, buildings, planning, drawings, documents, issues, progress, etc. The structure of the tables is such that in the future interfaces can be made according the IFC format of the IAI, and the BAS/Lexicon specification standard (ISO 12006/3 see [Iso2000]). Therefore it will be possible to easily connect other suppliers when a working interface engine to these standards is defined and implemented. Work on this is currently being done in several projects in the Netherlands like iBuild (see [iBui2003]).

Another spin-off of having a centralised database and design system is that it is relatively simple to generate virtual environments models of our products. Together with SARA (Stichting Academisch Rekencentrum Amsterdam) who have a high end visualization environment called a CAVE (see [Sara2003]), we can lead our customers through the building on a virtual real scale and discuss retail concepts, urban planning aspects, etc. Figure 5 shows a picture taken during a session with customers in the CAVE. It is the first floor. The image is rendered in real time from 4 positions in stereo so that the group of users is completely emerged in the computer generated environment.

Simpler portable solutions using only one screen are also very useful. Although the emersion is less a good idea of the project can be obtained and a lot of discussion about the project can be shortened because all parties involved share the same concept of the project.

Figure 5. Picture from Virtual environment of RSC-Oostpoort shop layout studie.

Currently we are working on the integration of the building scenarios with this kind of a virtual environment so we can detect all kinds of mishaps in the building process beforehand.

7. LESSONS LEARNED AND CONCLUSIONS

Implementing the process control and ICT environment is relatively easy compared to the role out to partners. There is a natural reluctance to accepting the ICT concepts like the Daily Scenario Sheet, the intranet based database and the way of working in 3D in general.

This has lead to some compromises:
Although we can produce daily scenario sheets on a real-time basis this is not practical. The saying that ‘the more precise one schedules the harder coincidence strikes’ is very much valid in building construction. Therefore we provide the daily scenario sheets only once a week for the ‘building team’ meeting which takes place ones a week.

The role out of the ICT is done in such a way that the users will benefit more than they have to invest in keeping the information up to date. Studies in shipbuilding have shown that measuring progress and matching it to planning is a difficult task (see [Los1994]). Co-operation can only be achieved when a win-win situation is provided.

Drawing exchange is done on a 2D basis using AutoCAD™ as an intermediate standard. Although collaboratively working in a 3D environment based on an IFC product model would scientifically be very nice, it would require all parties involved to have 3D systems which work.

It is economically not yet justifiable to get rid of 2D drawing altogether, though we hope we will get to the situation that working drawings will become available in ‘exploded view’ assembly instructions. The level of detail required can only be achieved at great expenses using a 3D CAD system. The trick is in knowing where 3D ends and 2D working starts.

Using an IFD system can be very profitable when applied to improve not only the product, but for all the process of building and the way in which win-win situations are created with co-makers. A classical construction company whose role it is to organise the subcontracting at the lowest price strangles all innovation done by the supplying industry. The normal percentage of R&D by industry is a few percent of the turn-over. This can never be achieved in the traditional way of working in building and construction. Innovation is not only product innovation, but also process and organisational innovation. The Dutch IFD programme supports this idea by subsidizing the added cost of building in IFD.

8. REFERENCES


Dame1997 J. Damen, et.al. „De Marktpotentie van IFD-bouwen voor de Nederlandse Bouwindustrie”, 1997

F2S2003 http://www.file2share.nl


Gree2001 J. Greenspan, B. Bulger, „MySQL/PHP Database Applications“, Hunger Minds, 2001

iBui2003 http://www.ibuild-online.com


Sara2003 http://www.sara.nl

Star2003 http://www.star.be
Automated Block-Laying, using the master mason

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ABSTRACT: Over the years, the art of block laying has been an important factor in building construction. Different cultures and construction experts have developed various styles, giving values to block laying. The major problem in block laying has been traced to the poor productivity of the masons. This has really hindered the construction time of most buildings. This project is an investigation into the use of automatic block laying machine or Robot known as “The Master Mason”. Each “Master Mason” is a triple-axis drive system with productivity of 100 (one hundred) blocks per hour and could be powered with a generator (solar or conventional) or direct electricity and has a rather low energy consumption and high serviceability of spare parts/components. It is easily affordable, considering the cost of each unit. One interesting aspect of this “Master Mason” is its ability to communicate with the Building or Project supervisor, using remote sensing and decoding techniques. The “Master Mason” is equipped with block haulage, placement, alignment and chucking tools. It is an essential equipment for the construction industry in the new millennium.

KEYWORDS: Axis; Chucking; Console; Drive; Sensing; Stroke

1.0 INTRODUCTION

1.1 An Overview Of Robots And Robotics

The word “Robotics” is synonymous with “Cybernetics”. According to Taylor (1978) Cybernetics is the study of control and communication mechanisms in machines and animals, covering all automatic control devices, selectors, relays, robots and computers and also the corresponding body mechanisms such as those of automatic balance, reflex action and cerebral association. When cybernetics is applied to electronic computers, more light is thrown on the function of the brain. “Mechanized or electronic brains” control the activities of Robots in the engineering industry. In Engineering, Robots are electro-mechanical devices that carry out the normal production processes or services of human beings. For instance, there are Robots that make, clear tables, serve people and wash dishes/pots. There are others applied in the production industries to increase productivity and reduce wastes. Generally, according to DRO (1979) Robots are seen as variable – speed systems, controlled by programmable microprocessors, via remote control consoles. Robots use different power drive systems in their mechanisms. While some use Ball screws and servo motors, others use air pressure or hydraulic pressure etc. These drive systems depend on the demands of the proposed function of the Robot. Again, Robots are fashioned to carry out the exact functions of workers or human beings in their natural order. Their features must therefore have some degrees of freedom e.g the arms or legs or heads must be able to rotate about some specified degrees or radians. The Robots should also be able to move around, if necessary, about some defined axes (x, y or z). The various, designed and specified distances along all these axes, are called “work strokes”. The x-axis work stroke may be different from the y-axis work stroke etc. Also, different motors control different axial work strokes. Also, different motors control different axial work strokes. These motors have different speed ranges, depending on the function & timing.
At the end of the production of any Robot, certain standard recommended tests are administered to the Robot. A good time is necessary to prepare test procedures, observe the tests, collect data and prepare test report data and test reports. Robots are usually tested by a team (see fig.1)

Companies with challenging ingenuity (and experience in microprocessors, lasers, fibre optics, exotic material) have demonstrated engineering, scientific, and manufacturing capabilities in the development design, manufacture, and operation of industrial Robots, automating some sensitive activities in the industry.

The art of block laying is one of the sensitive activities in the building industry. This is done, using concrete blocks. There are many types of concrete or sandcrete blocks but these come under any of the following families;
(a) Solid tongued and grooved
(b) Cellular, plain ends.
(c) Keyed common
(d) Cellular, tongued and grooved
(e) Cellular, plain ends.

(see table 1)

1.2 Manual Block laying

1.2.1 Work Procedure

The normal work procedure for block laying is as follows;
(a) Define your building profiles, during and after earth (foundation) excavation and concrete blinding.
(b) Put the end blocks (i.e 1st and last blocks) without chucking them in place.
(c) Align the end blocks using a taut rope or line (one by the side and the other on the top) This ensures a straight line. (N/B. leave the rope or line until all other blocks are put in place.
(d) Plum the end blocks to make sure that they are in line with one another and have their tops at the same level.
(e) Put other blocks in place, in between these two end blocks and plum them together as before.
(f) Remove the alignment ropes and chuck the blocks together, using a pre-mixed mortar.
(g) Rub the joints to smoothen them.
(h) Start the laying process/cycle again.

1.2. 2 Limitations Of This Practice

(a) The mason easily gets weak.
(b) His productivity is low, because his activated time is low.
(c) His accuracy is low.
(d) Much material (mortar) is wasted.
(e) Production is not economical because of the dynamic increase in labour costs.

2.0 METHODOLOGY

2.1 Field Studies

Various workstudies were carried out on experienced, professional brick layers (Masons) at standard construction companies. Idle times were matched with activated times of these masons and their work methods and productivities were noted over a period of 12 (twelve) months. These results from different companies were put together, stochastically and averages were worked out.

2.2 Robot Design

Different designs of Robots were made initially to meet the construction process requirements of block laying.

2.3 Computer Simulation

Simulations were made using the computer and the “master mason” was adopted as the best Robot that could achieve economy and productivity.

2.4 Automated Block laying Procedure

Every “master mason” has a “servant”. The servant hauls the blocks, lifts and puts them in place, while the Master Mason aligns, chucks the blocks and makes another mortar bed for the next block course. This cycle continues until it is stopped by the Building Supervisor on the control console.

3.0 DESIGN ANALYSIS OF MASTER MASON

Generally, this Robot is operated by a programmable microprocessor with a 32k Ram.
3.1 The Auto-arm

Every master mason has two automatic arms, each fitted with a gripper. Every auto-arm is designed to rotate 90 degrees (1.5 radians) around the base (the shoulder). This degree of freedom enables the master mason to pick up blocks from the floor, put them in place and work on them. Within a 50.80 cm radius, from the block wall. The auto-arm conforms with the specified maximum length of the x- and z-axes work strokes. Each auto-arm is operated by four stepping motors, with well calculated work speeds. Again, calculations were made to determine the gripping pressure of the wrist claw of this master Robot on the block units. It was found out that enough pressure could be exerted on the blocks to lift and work on them with minimal damage. This pressure was observed to be directly proportional to the unit weights of the blocks.

3.2 The Auto-legs

These are legs that are operated on the y-axis, with a stepping motor and Ball Screw Drive. In each run, the motor reverses direction in one quarter of a second. The torque is designed to fall within acceptable specifications. The work strokes, speeds and overshoot are also within limits. Manual scaffolding is no more necessary. The Auto-legs allow the Robot to stoop and pick up blocks and hoist them at desired heights or levels.

3.3 The Head

Each master mason’s head is equipped with a voltmeter, an ammeter, and a thermometer to give readings of voltage, current and temperatures of the system, respectively. It also has a compact mouth or speaker that alerts the Supervisor in case of any internal danger.

3.4 The Working Trunk

The Trunk is designed to have complex meshing gears to facilitate movements of the mechanical parts and to automatically lubricate internal parts so as to reduce high-noise levels/frictions and consequently internal temperatures.

3.5 The Mortar Feeder.

This chute has an automatic control/gate valve, which admits or shuts off mortar supply to the Robot. It is fed directly by a mobile mortar mixer, with pre-mixed materials.

4.6 Operation Sequence.

Operations set up a work for the Robots, positioning them within acceptable axial work strokes. The operators move outside this work post to a remote control console. At the console, they dial in the desired x- (horizontal) axis data, the z-(transverse) axis data, the number of stroke, and the speed of the drive motor. They also input the y-(vertical) axis fall and arise distances and the distance the transverse motor moves the blocks to position. The system now starts and completes cycles accordingly until further instructions are give.

4.7 Productivity

the “Master Mason” increases productivity by 800%, and cuts mortar waste by 97%, block waste by 85%.

5.0 CONCLUSION

The “Master Mason” is a wonderful worker. All the components of its system, are readily available and affordable. It is so cheap that every construction company can afford to have one. It is highly serviceable and could be maintained or repaired if need be. It is also of a high productivity and precision.
Figure 1 Program Organization for Robot.

Table 1: Concrete blocks Specifications

<table>
<thead>
<tr>
<th>Thickness &amp; type of block</th>
<th>Dimensions of face (length x width) (in mm)</th>
<th>Block weight (in kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 mm solid, tongued and grooved</td>
<td>400 x 200</td>
<td>6.3</td>
</tr>
<tr>
<td>100 mm cellular, plain ends</td>
<td>450x225</td>
<td>9.5</td>
</tr>
<tr>
<td>140mm cellular, tongued and grooved</td>
<td>450x225</td>
<td>10.9</td>
</tr>
</tbody>
</table>
Figure 2. Typical Hardware Breakdown Structure Of Robot.
6. REFERENCES

- DRO standard 239-79, standard for the Design of Domestic Robots, ABC Institute, South Gulch, USA.
- Debenham, Microprocessors. Principles and Applications, Pergamon
- Dummer, Electronic Inventions of Discoveries, International Library, Manchester VPTEV, 3rd Edition,
- Pergamon International Library, Manchester
Innovation of the Dutch window frame: The Kapla® Concept

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ABSTRACT: The development of the Kapla® window frame means a breakthrough in the timber window frame market in the Netherlands. This development is a typical example of a combined process and product innovation, a joint project with the relevant branch organizations. The success of the Kapla® window frame proved that the methodology developed works well for such innovations. Special tools for mounting the window frame have been developed.

KEYWORDS: Building System, Window Frames, Multidisciplinary Design.

1. INTRODUCTION

Within the building process in the Netherlands, the window frame has a special place. Traditionally, the window frame is placed first, before further work to the façade is started. In this process, the window frame is used as the basis for positioning the other parts in the façade, such as the masonry. This gives a typical Dutch image of a building site in the early stage (see Figure 1.). The vulnerable timber, primed but not finished, window frame has to withstand all weather conditions in the building stage. Also, all materials needed within the building are transported through the frame, frequently leading to damage and therefore extra costs.

In this paper, an innovative change of the Dutch window frame is presented. This innovation could not have been successful without cooperation between branch organizations of carpenters, brick factories and the window frame industry. The innovation described is a success thanks to the integral approach of innovation of the product and of the process.

2. THE TRADITIONAL DUTCH WINDOW FRAME

In the current Dutch building practice, the window frame has an important function for the brick laying process. The bricklayer uses the window frame to outline the brickwork. This means that the window frame is placed at the early stage of the building process. This leads to a number of problems:

1: The window frame is present during the whole building process, and has to withstand all influences year-round. Building materials, workers and equipment are entering the building through the frames, and weather effects can freely effect the frame. All this has a negative effect on the quality of the window frame. Often, a large
amount of small damages are present on the window frame when the building is finished.

2: Many parties are involved in the mounting of windows and doors, for:

- Positioning
- Mounting the frame
- Glazing
- Mounting doors
- Painting
- Plastering the edges

The latter activities are done at the final stage, just before finishing the building. This increases the need for coordination needed throughout the process, and consequently the costs.

3: Most of the work on the frame is done on the building site, from the outside of the building. This is very labour unfriendly, and leads to planning problems in case of bad weather.

4: The traditional window frame is not demountable;

5: The design lifetime of the brickwork usually determines the design lifetime of the building. Window frame usually has a shorter lifetime.

As a result, in the Netherlands, often tropical wood species are applied. Also, there is a growing dissatisfaction about:

- The uncertainties in the planning of the weather sensitive activities
- The life of the frame compared to the life time of the building;
- Restricted productivity on the building site;
- Use of tropical wood in buildings.

It is not possible to mechanize the painting and glazing process on the building site. Therefore a new approach to the typical Dutch, timber, window frame was needed: A multidisciplinary, sector-exceeding approach was chosen, to come to a combined product- and process innovation. This innovation would also open the way to use other wood than tropical wood.

3. COMBINED PROCES AND PRODUCT INNOVATION

Innovation in building are initiated by different parties. Traditionally, two types of innovation are applied, which are the domain of different parties:

- Product Innovation is the domain of the building industry. The industry needs to innovate to continue their business. Most parties have an R&D department. The industry is very money intensive, has a long-term vision and has continuity in employees. Most innovations concern innovations on the product itself or on the production process. In situations where mounting is also done by the industry, process innovations are influenced or encouraged.
- Process Innovation is the domain of the building contractors. Innovations are motivated by money-saving or by rules by government, e.g. for working conditions. Most parties do not have an R&D department.

Product innovation and process innovation are incremental innovations. Small steps lead to a more and more optimised product or building process. In current Dutch and future international building codes, performance based design becomes more and more important. Design rules are no longer based on products, but on the functions that need to be fulfilled. This opens the way for a new approach of designing building parts, and requires a breakthrough for both the building industry and the building contractor. Such a breakthrough can only be possible by innovating both products and process simultaneously. These innovations are characterized by:

- Dissatisfaction about the functions that are fulfilled by a building part, which can not be solved by product or process innovation solely.
- Involvement of branch organizations of both building industry and contractors.
- Projects over many years, with increasing role for the building industry.

These innovations are necessary in cases where building parts are built from mass product and assembled by many, mostly small, companies. In the Netherlands, this is typical in building domestic dwellings. In many cases, these innovations include one or more forms of mechanization or prefabrication.

The development of the Kapla® window frame is a successful example of such an innovation. The branch organizations of the joiners, brick layers, and contractors have supported this project from the beginning.
4. THE KAPLA® PROJECT

The idea for developing an innovative window frame for the Dutch market, based on a change in both the product and process, was motivated by the list of problems in the traditional window frame, both in the product (damaged window frames during erection) and in the process (co-ordination between parties, and labour friendly working).

4.1. The project team

A steering group guards the process of the project, with the financing parties and TNO as secretary. The work is done in several working groups, in which both industrial parties and building parties take part. These working groups are led by a TNO project leader.

The Kapla® project was initially supported by:
- Branch organizations of Building Contractors, currently BouwNed;
- Branch organization of joiners NBvT;
- Branch organization of brick layers AVM;
- The silica block industry CVK;
- The union of Dutch Architects BNA;
- The labor union FNV;
- Building product industry

4.2. The structure of the project

The Kapla® project is one of a range of projects in which combined product and process innovation is done. These projects are so-called building-part projects. These project are structured by a phase-by-phase approach. The phases in the Kapla® project are:

1: Exploration phase
In this phase, a neutral party (in this case TNO) explores the need for innovation of the building part under consideration. Both the needs for product and for process innovation are investigated. This part usually is paid from subsidies, and none of the intended parties are yet involved, other than as interviewed partners. This phase typically takes one year, and is finished by a go-no go decision.

2: Project definition phase
If the needs for innovation are clear, the project definition phase is initiated. In this phase, branch organizations are usually contributing to the project. In this phase, the requirements for the final result of the projects are defined. This phase typically takes one year.

3: Development of concepts
The required result may be defined in terms of one or more concepts. For the Kapla® window frame, a new concept was required, with the following specifications:
- The new concept has to fit into the building process, where the brick layer uses the window from as basis;
- There was a need for an early closing of the window spaces during the construction phase;
- Tools need to be developed for mechanized mounting of the frame;
- The price for this new concept is not more than the traditional concept;
- A shift of labour from the building site to the factory is needed.

Based on these demands, the Kapla® window frame was developed.

4: Building of prototypes and testing
When the concept is ready, prototypes have been tested in the laboratory to prove the performance. Application of the Kapla® concept in a real building was used to test the applicability of the concept in full scale, and as a check whether the specifications of point 3 are met. After successful implementation, the new window frame was made available for small-scale projects.

5: Introduction in building practice
The Kapla® window frame was applied first in projects with domestic dwellings. The results were used to improve the window frame concept. The mounting of the window frames was coordinated and monitored by the project team. After these initial projects and after making necessary improvements, the Kapla® window frame was ready for introduction in practice.

6: Knowledge transfer and training
For a successful implementation of the new process and products in the existing process, clear and complete knowledge transfer should be aimed for. Digital techniques, e.g. video-DVD’s are used to show the advantages of the newly developed product and process. Video presentations and online information (see e.g. figure 2) are available for:
5.1. Process innovations

A temporary window is placed at the early stage of the construction of the façade. During construction of the building, no work is done on the window frame. At the end of the construction period, the temporary window is removed and made available for recycling. The Kapla® window frame is manufactured in the factory, including priming, finishing and glazing. It is installed by using a special device and a crane.

In table 1, an comparison is given of the activities needed in installing a traditional and a Kapla® window frame.

5.2 Product innovations

The concept of a temporary window is not new, but the way this window is fitted in the structure, using the mounting structure for the Kapla® frame is innovative.

A special Kapla® strip was developed to make the placing and mounting of both the temporary window and the Kapla® frame easy and accurate. This strip is giving a contribution to the air tightness of the building and is also basis for plastering of the edges.

5.3. Mechanization

Special tools have been developed for transporting and mounting the Kapla® window frame. The window frames are placed on a special structure, which ensures an easy to handle process on the building site (see Figures 3 to 5).

For placing the frame, one person is handling the mobile crane which carries the special Kapla® hook. The window frames are carried to the
position where the frames are needed. Two persons guide the frame from the inside into the position. Using three specially developed clips, the frame is secured, and using 10 bolts, the frame is fixed in its final position. In this way, about 2 houses per day are served.

6. CONCLUSIONS

The Kapla® concept is a successful alternative for the traditional Dutch timber window frame. The methodology developed for this project has proven its applicability. The national introduction is coordinated by the Timber Information Center in the Netherlands. The amount of Kapla® frames installed is small, but every year an increasing number are installed. The methodology developed forms the basis for further process and product innovations, such as new concepts for the building façade, floors and installations.

The price for a Kapla® window frame is potentially smaller than the traditional frame. An increase of installed Kapla® window frames is necessary to achieve this.

Experience with many projects, including several different windows and doors, is needed to identify the need for improvements.

7. ACKNOWLEDGEMENTS

The development of the Kapla® concept could only be possible by the financial support of The Dutch Ministry of Economic Affairs, branch organizations for building contractors (currently BouwNed), joiners (NBvT), brick layers (AVM) and industrial parties (Ubbink, Illbruck, Holonite).

8. REFERENCES

Information on the Kapla® window frame is available on the internet:

http://www.tno-kapla.info/