MASTER

Prototype of a dynamic building

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PROTOTYPE OF A STATIC BUILDING

Dynamic
“Close your eyes and open the box. Everything is possible”

Schrödinger’s Cat
INTRODUCTION
Our built environment displays a major and possible unwanted difference towards the society dwelling within; the built environment is static and steady, while our society is dynamic and unsettled, changing constantly at an seemingly endless exponential perspective. Innovative structural engineered buildings carry the potential to take this gap away, through reflecting the dynamics present in our society; a dynamic building. To successfully keep up with the constant changing environment it is necessary for such a building, to be able to interact and behave intelligent during the exploitation period.

Both main issues, a dynamically structured building and intelligent behavior, have been investigated through the development of a physical prototype. The method used for the development process is called "Rapid Prototyping".

The structure of the build prototype provides the necessary stability, strength and movement freedom in order to behave dynamically. The added hardware and software regulates the behavior and movement related to input from the prototypes’ surrounding.

The prototype gravitates itself in order to maximize the received light and reacts to being touched. Both applied examples of the possibly different added sensors and their behavior.

Constructing dynamically and intelligently behaving structures results in a more natural environment in which society and built environment reflect each others behavior. Clear examples are the elimination of wind tunnels in between large apartment buildings due to a moving facade, automatically appearing sound barriers, maximizing solar energy with a solar tracking shape, roofs shaking snow off themselves, and shrinking building footprints after an office has close.

The influence of a dynamic building to the use of the interior, current construction methods and building materials are the most challenging to overcome, however not inconceivable. Numerous architects, contractors, project developers and universities are currently developing new kinds of technologies in this sphere of work. Aedas, M.I.T., ORAMBRA, Kas Oosterhuis, Christian Derrix, and David Fisher are some examples.
Preface

This report is part of the graduation project "Prototype of a dynamic building" within the Mastertrack combination: Architecture and Design Decision Support Systems.

One of the most recent developments within architecture, which gradually gains more followers and enthusiasts, is digital design. Generative Architecture, Parametric Design, BIMs, Living Building Concepts, Interactive Architecture, Real Time Behavior Design, and Programmable Architecture together form a relevant draw from the collection generally made possible through CADs & CAMs.

Examples of prominent architects involved in this area are Massimiliano Fuksas, architect from the recently finished Blob in the city center of Eindhoven, Kas Oosterhuis, from the architectural firm ONL and the Faculty of Architecture at Delft, and Tristan d’Estee Sterk from the architectural firm ORAMRA. Where the name of the last mentioned firm is actually an acronym for "Office for Robotic Architectural Media & Bureau for Responsive Architecture", emphasizing the sphere of action.

Usually dynamics finds its transcription to architecture through the physical static tectonic of the used volumes. However nowadays dynamics finds its transcription to architecture more often literally, through the combination of the possibilities with CAD & CAM and the current architectural tendency. By doing so, an architectural, physical dynamic building is able to display intelligent behavior. For example a physical dynamic building is able to mimic the behavior of the sunflower; tracking the solar movement throughout the day while maximizing the efficiency of solar energy. Another example is a dynamic soundbarrier designed by Kas Oosterhuis;

which only erects when the sound of a passing train needs to be reflected.

Dynamic architecture, in this sense the more physical explanation of the subject, is an architecture of possibilities enabling intelligent and reactional behavior during the exploitation period; where generally a building is dependent on the correct analysis and assessment of eventually unchangeable static design decisions. This development not only changes the final product during the exploitation period but also the design process and methodology.

In "Causation or effectuation; towards a theoretical shift..." Sarasvathy, S.D. (2001) Sarasvathy describes a parallel development in the area of technology entrepreneurship. She expounds the theory that nowadays in technology entrepreneurship it’s more important to be able to control the future rather than acting towards a predicted one. So, to return to the subject, not the analysis and assessment of the future, and the transcription to architecture are important, but rather the control during the unpredictable various developments of the future.

(1) Mastertrack combination - The faculty of Architecture, Building and Planning provides several masters porgams as well as combined programs such as the ARCH + DDSS program in which both compulsory main study parts of each master must be completed successfully. (2) Generative architecture - Architecture based on generating automated and scripted forms. (3) Parametric Design - Developing and generating forms according to combined parameters (4) BIM - Building Information Modelling (5) CAD - Computer Aided Design (6) CAM - Computer Aided Manufacturing (7) Dynamic and kinetic - Dynamics incorporate the actual forces in play in moving assemblies while kinetics only deals with how things move in assemblies.
Motivation

The choice of this subject results from the combination of personal skills and characteristics, and recent developments. First and foremost I am a person who is constantly looking for new experiences, fields of knowledge and challenges that can be combined to assess my competence and eventually gain new experiences and knowledge. The cradle of the choice to expand my architectural career with Design Decision Support Systems; a new challenge to keep my learning curve steep and to supply in the need for new experiences and knowledge.

The cause and key question to this subject is based on an observation I did four years ago: Why do we find ourselves in such a slow developing built environment in contrast to the development speed of our society? For example, before the start of the construction of a house, generally a year after commission and design, new developments have rendered parts of the design obsolete. New insulation materials, different types of bricks and cheaper or stronger concrete. However, the waste of resources, it is the architectural elements of the concerning project I worry about the most. In this case, maybe a sightline from inside the building directly towards a picturesque view outside was part of the architecture. If that particular picturesque part of environment changes this physically fixed and environmental dependent part of architecture turns obsolete. These numerous and common changes in the (built) environment influence the way in which architects (should) design. From my opinion, the design process and methodology should therefore shift from predicting the future to controlling a future, similar to the proposition of Sarasvathy as depicted in the preface, in order to decrease the gap between our slow developing built environment and our society.

Architecture nowadays finds itself in a phase of digitalizing; in which methods and elements of expression are redefined and critically assessed. To me the most interesting part of such a phase is the often drastically changing manifestation of architecture and its elements of expression. A clear example is the period of the Modernists in the early twenties, when light and concrete where combined in ways never seen before, to eventually result in the new norm. Despite the similarities of these phases, the current phase of digitalizing in architecture and the phase of the Modernists, an important difference should be noted. Nowadays almost every development seems exponential, and even so the development of methods and elements of expression to architecture. In this way, compared to almost only the new use of light and concrete in the time of the Modernists, to which architecture had to formulate new proper application norms, nowadays numerous new methods and elements of expression come to existence simultaneously, and architecture seems to lag behind in again formulating the new proper application norms. It seems to me that architecture currently is an art threatened to be taken over by the elements in which it displays itself. Glass beams, electricity generating tiling, programmable cladding, organic growing walls and to personal presence reacting panels. All elements of which before the art form architecture can formulate proper application norms, are rendered obsolete by the use and development of new, similar and better performing elements. This seemingly exponential quantitative development of elements possibly useful to architecture manages to break the essential grip the art form architecture should have upon them. The art is being overtaken by its elements of expression through the sheer volume of possibilities.

How can architecture restore this essential grip without stalling or limiting the development potential of these elements? With this graduation project, the acquired knowledge and experiences during the development of the dynamic prototype eventually provide a better insight in how dynamic architecture should look like in the future, and if it is able to regain control over it's fast growing elements. As a future architect, this subject fundamentally motivates my (re)search.

(1) Choice - Normally a given subject is treated in a group of students. Because of the Mastertrack combination the subject was free to determine. (2) Digitalizing - The change architecture currently is going through due to the larger set of possibilities with digital design (CAD & CAM) and projects growing more and more in complexity. (3) Modernists - Persons in the late 19th, and early 20th century, who felt the traditional forms of art, architecture, literature, religious faith, social organization and daily life were becoming outdated in the new economic, social and political conditions of an emerging industrialized world.
Goal graduation project

This project results in a physically build and digitally developed prototype of a physically dynamic structure to react and interact with one or more external influences. The developed prototypes' structure will be used as basis for a case study. The main research question will eventually be discussed.

Main research question
How should the structure of a dynamic building look like and what intelligent behavior should it display?

This question comes forth from the more sociological related issue concerning the possible elimination of the static build environment. In order to do so successfully, it is firstly necessary to develop such a system and secondly, to evaluate its performance. The final goal is then to conclude whether it is a desirable development for our built environment.

Sub questions
The subquestions are more specifically formulated in order to conclude separate parts of the complete subject.

1. What kind of shape does one element of the system need?
2. What kind of material can be used?
3. What types of intelligent behavior are a necessity, what desirable and what redundant?
4. Is it desirable to build dynamically in the future?

Method
In order to develop a working prototype the known method "Rapid Prototyping" will be used as design process. This specifically type of process will be discussed separately later on. In short the main difference with a normal design process is the rapid consecutive development of slightly different physical products in order to gradually develop the final and main prototype. The final prototype relies heavily on evaluation moments in between, of the separate products.

Social relevance
This research, eventually resulting in a prototype, will bring up a relatively new issues, concerning the, statically, built environment. In a society where everything seems to develop itself exponentially, the built environment lags significantly. Does this lagging process naturally work as a necessary counterbalance in order to supply a solid foundation for humanity or should it change and adapt the attitude of the rest of the society seems to dominate? Should the built environment display dynamics?

Although the main scope of this research does not provide an answer to this more psychological and philosophical rooted topic its results will provide new insights in the possible outcome of this discussion. Which parts become dynamical? How does this influence the users? How does this influence our built environment change? And finally, the more subjective part of the research, is it desirable to build dynamically in the future?

Scientific relevance
Regardless of the final outcome whether or not it is desirable to build dynamically, this research will provide useful insights and information to the architectural sphere of action. Due to the necessary iterative research method, to prevent decisions and assumptions from turning obsolete during the process, concepts of strength, stability, style, esthetics, functionality and architecture itself will be redefined. The research combines a number of divergent fields of knowledge in an innovative way. For example knowledge of construction technology and mechanics to make the prototype kinetically and dynamically functional, knowledge of architecture to embed the prototype in its social and environmental context, knowledge of building technology to provide the necessary wind- and water tightness and knowledge of product development in order to produce the fundamental element correctly.

The scientific relevance is particularly found in the prototype forming a new process-oriented and methodological approach to developing a physical end product for the built environment, which is not yet commonly seen design approach.

Expectations
The final prototype will render useful insights in the differences between the current static built environment and the possible dynamic built environment. Insights concerning the construction methods, exploitation period, the ecological footprint, useful intelligent behavior and the influence dynamic structures have on their end users will be the most likely. The material of which the prototype eventually will be constructed from, when put to use as an actual building project, will be the most challenging part. Structural demands concerning stiffness and stability in multiple directions instigate this issue.

(1) Physically build - Referring to the prototype (2) New issues - Relatively new issues like durable production, the use of energy, the ecological footprint and building costs. (3) Philosophical rooted topics - Because the scope of this topic is related to far future developments
Preliminary research

This graduation project initiated after a preliminary research on the topic dynamic architecture in a broad sense. The main part of this research was devoted to investigate the state of the art concerning the relation between the topics dynamics and architecture, in order to generate a useful shortlist of recommendations as input for the final graduation project. Recent studies, designs and prototypes documented on different types of media where treated. The introduction depicting the cause and context of the subject for the preliminary research is treated below, followed by an introduction of related projects.

The ideas of an architect, conventionally referred to as the concept or concepts of a building, are usually formed at the cradle of a project. Usually a year after, the actual construction initiates. Concerning Senter Novem, and in the case when such a project is meant to serve a household, 75 years later a new building will erupt on the exact same location.

"...the concept is a continuous process"
Reading "De zin en onzin van concepten" Misak Terzibaslan 2008

"...we are living in instable times in which everything changes; the form evolves"
Reading "De zin en onzin van concepten" Herman Hertzberger 2008

"...the goal wasn't creating a dull unity, the individual properties decay, their footprint remain"
Reading "De zin en onzin van concepten" Christoph Kohl over Brandevoort 2008

"Homes have an average lifespan of 75 years; is that a realistic assumption?"
SenterNovem 2006

"The top 10 in demand jobs in 2010 didn't exist in 2004...
Years it took to reach a public of 50 million people; Radio 38 years TV 13 years Internet 4 years iPod 3 years Facebook 2 years...

This year 4x10^19 bytes of unique information will be generated this year; in total more than the last 5000 years...

Every two years the amount of technical information doubles; for a TUe student this means that by the start of his third year, half of what they've been taught is outdated...

Estimations are that by the end of 2013 a supercomputer exceeds the computational capabilities of the human brain...

Estimations are that by the end of 2049 a supercomputer exceeds the computational capabilities of the entire human species (and only for a whopping $1000..."
Video "Did you know 2008 3.0" YouTube 2008

We are living in exponential times in which architectural concepts decay through their physical static translation in a strongly dynamic founded surrounding. Do we need to close the gap in between? Do we need an architectural resolution?

(1) "de zin en onzin van concepten" - A series of presentations arranged around the subject "the usefulness and nonsense of concepts" (2) Senter Novem - Currently AgentschapNL
Related projects

Name
GINA

Project
BMW concept car

Year
2002

Industry
Automotive

Designer / manufacturer
Chris Bangle

Location
Germany

This concept car is the first to introduce a dynamic designed skin. The few flexible steel and carbon fibre wires shape the car and provide the necessary movement for some parts: the hood, the lights, the doors, the rear spoiler. The skin is made of a strengthened flexible textile. This design is strongly related to the subject of the preliminary research due to the new approach of the design team: a skin able of constant adjustments, within certain borders, related to the context of use. In this way, parts of the car remain useful while the context changes.

(1) GINA - Acronym for Geometry In N (infinite) Adaptations (2) Certain borders - The borders are the defined physical limitations in movement or the programmatical minimal and maximal borders.
Name
Dynamic skyscraper

Project
Rotating apartment building

Year
2008

Industry
Architecture

Designer / manufacturer
David Fischer

Location
Dubai

This enormous building project design by David Fischer consists of stacked prefabricated rotating elements. This project is an example of how the dynamics of a building are not interactively related to its environment.

This building concept, with passive dynamics, is an example out of the vision of the preliminary research. It does display a certain degree of dynamics but does not incorporate any interactivity towards its surroundings; rendering the dynamics less useful for future adaptations.

(1) Passive dynamics - The dynamics applied with passive dynamics aren’t linked to any kind of input resulting in a non-interactive dynamic system. (2) Individual muscles - Specially designed and developed for this project are the flexible and controllable, muscle-like cables setting the prototype in motion.

One of the several moving pivoting principles of the Dynamic Skyscraper by David Fischer 2008
Muscle

Programmable prototype

2003

Architecture

Kas Oosterhuis

The Netherlands

This programmable prototype can reconfigure itselfs mentally and physically, without considering to completely displace itself like the Walking City as proposed by Archigram in 1964.

Motions of the individual muscles: change the length, the height, the width and thus the overall shape of the Muscle prototype by varying the pressure pumped into the 94 swarming muscles.

Such a method, changing shape according to input from the prototypes' surrounding, is the core of the subject for the preliminary research.
Name
Institute du Monde Arabe

Project
Interactive facade

Year
1987

Industry
Architecture

Designer / manufacturer
Jean Nouvel

Location
France

The facade system of the Institute du Monde Arabe designed by Jean Nouvel regulates the amount of light entering the building. Small and large diaphragma's open and close throughout the day to adjust the amount of sunlight passing through.

Such a system is a clear example of how interactive systems can combine the esthetical with the functional and practical. However, the downside of this system proved to be the lifespan of the multiple used parts; malfunctioning almost completely nowadays.

(1) Institute Du Monde Arabe - A building in Paris, France, housing a museum for Arabic art and a library (2) IA#3 - IA, short for Interactive Architecture, is a series of small booklets published by the design group of Kas Oosterhuis displaying their recent projects and developments.
This wall system is composed of several moving wall elements. Every element consists of a large moving actuator reacting according to the input and transcription the software system in the element receives.

This interactive interior wall is a good example of a possible way to translate the presence of persons into a reacting system. This design would be more interesting if combined with constructional demands.
Related papers
A range of papers and texts have also been taken into account, next to the presented projects.

Shape Control in Responsive Architecture
by Tristan d'Eetle Sterk, Chicago 2008
This paper states that controlling a shape in architecture is based on two principles:
- the knowledge that quality and function are strongly related to the shape of the building
- the new idea of adding intelligent systems to a building can positively contribute to controlling the shape
The conclusions of this paper is that the use of such systems requires an evaluation concerning the conventional methods in architecture and construction.

Hyperbodies
by Kas Oosterhuis, TU Delft 2006
Hyperbodies are, according to Kas Oosterhuis, buildings who can constantly adjust their shape. Hyperbodies react to the input of users or its surrounding to initiate their change of shape. This interaction comes forth from a flow of data towards the surface of the building (the hypersurface) it's the task of the architect to conceptually program this specific interaction.

Biosynthesis
by LabStudio 07/08, University of Pennsylvania 2008
The initiative from LabStudio, the collaboration from where this paper was developed, started to investigate the overlap between the fields of work of architecture and biology, and how it can effect the future vision on architecture and biology. These researches cover the subjects of the fundamental principles of life and their historical and modern relation to generative design.

Absent Bodies
by Ignasi de Sola-Morales 1997
Ignasi de Sola-Morales wrote this text in 1997 and exposes the gap in which architecture finds itself nowadays; should architecture admit itself to the type of the dynamic and fragmented environment created by mankind or should architecture counter this movement? According to Sola-Morales the human kind finds itself nowadays in a fragmented existence. Architecture should admit this existence to create a convincing display instead of creating resistance.

(1) Evaluation - This evaluation and reconsideration of conventional methods is necessary because the end product of architecture changes intensely. The known methods, tools and knowledge may therefore become obsolete in some parts. (2) Data recording system - Such a system records input data from the buildings internal and external surroundings. (3) Similar concepts - Like the "muscles" designed and developed by Kas Oosterhuis, the definition of a muscle in architectural terms differs heavily from the biological one. (4) LabStudio - Within the Sabin-Jones LabStudio, architects, mathematicians, materials scientists and cell biologists are actively collaborating to develop, analyze and abstract dynamic, biological systems through the generation and design of new tools.
Photograph of the interactive tensegrity structure prototype
Orambra 2008
First prototypes
The following prototypes have been developed in order to investigate different forms, connectivity, scalability, and degrees of freedom of possible dynamic structures.
As depicted under the scientific relevance, a conventional process and research method with an accompanying planning is of no use. Such a planning is based on decisions related to a predicted outcome of the future. When the built outcome of such a process thus switches from typology, from controlling a predicted future to controlling an unpredicted one, it is also necessary to switch from the conventional fast converging design process; to prevent the prototype from falling under the same category buildings I'm questioning in this graduation project. The change from a static end product to a dynamic product has a direct influence on the process and method.

Practically this means that the separate products part of this research must be made parallel but separates to each other and that the necessary convergence, the interrelated design decisions, is found at a simultaneous evaluation moment when the products reach their iteration completion. Of course, after this evaluation a next iteration for each parallel but separate product process can start again. The goal of the evaluation is to create relations between products. Adjusting the outcome of products according to such evaluations is then necessary until finally the iterative process reaches a stable state in which no adjustments are to be made again.

An unpleasant byproduct of this new parallel production process, used with the graduation project, is the unpredictable time of each iteration. There are numerous conventional methods of planning and predicting the necessary time to produce something, for example "Methode Flapper", but not in a similar iterative process like this. To transpose to this iterative process it is possible to first calculate the total time it would normally take, and then to divide this total into unequal iterative parts. (Unequal because generally each following iteration takes less time.) Then, these unequal but divided parts can be placed in time; with in between them the evaluation moments in which the design decisions and basic concepts underlying the products will be made.

In short, the design process used in the graduation project consists of divided, parallel placed, timewise converging, iterative product processes in which a strong interrelation is reached through evaluations. This design process is combined with the known method for developing physical prototypes called "Rapid Prototyping".

**Rapid prototyping**

Rapid prototyping is a methodology to systematically develop physical models, called prototypes, of new and innovative ideas. This methodology consists of the following steps:

1. Defining the necessary functionality of the prototype
2. Sketching and modeling the prototype with CAD
3. Producing the prototype with CAM
4. Evaluating and possibly adjusting the prototype

The CAD part are usually realized with 3D software packages like 3D's MAX, Rhinoceros, VIZ and Revit. The CAM part can consist of production methods to translate the digital 3D model to a physical prototype like stereolithography, fused deposition modelling, laminated modelling or selective laser sintering.

The most important element of Rapid prototyping is the iterative part of realizing prototypes with this method. In the first iterations it's important to vary the basic assumptions underlying the prototype to create several possible physical solutions. After a number of prototypes have been created, one type meeting the functionality the most, is selected. This prototype is then developed into further, more detailed versions, with smaller variations.
American factory floor in 1920; a classic "conveyor belt" process
by Anonymous 1920
The case study

The case study is put together in order to evaluate the prototype under the conditions of an ordinary design process. Therefore a set of basic assumptions is necessary to guide and restrict the design process and finally, to draw conclusions of the functionality of the prototype for such a process. The case study contains several subjects. Together they stretch across the complete width of an ordinary process. The sections concerning these subjects conclude with the basic assumptions to which the final design is realized.

Location
Where does the prototype display its behavior at its best? Where is the prototype able to collect enough and relevant input to show its interactive capabilities?

Program of demands
In this category the program, of the prototype functioning as a building, will be explained. Which functions are needed and how they relate to each other. Furthermore, quantitative information will be given for example the number and type of sensors and square meters per function.

Architecture and interactivity
Here, the underlying theories, used to determine the overall appearance of the prototype, are caught in a design concept. For example, why the building looks more like a fragmented spiky shape than a smooth blob.

Most important is the impression the project leaves on its social- and build environment in difference with the ordinary static buildings. The architecture of the project should embody this concept.

Installation
Here the underlying behavior of the prototype is explained. The influences to what the prototype reacts, how it reacts and what kind of soft- and hardware is necessary to provide. Also the more standard installation parts are treated; how the building is heated and cooled and where those installation elements are placed.

Materials
The materials used to express the architectural concept and the materials necessary for construction are depicted under this part. It is possible that some materials needed for the project aren’t yet existing; the importance of the project lies within investigating the concept of the dynamic possibilities for such a building. For this reason it is for some materials justified to eliminate the existence.

Structural engineering
The engineering fundamentals, guiding the forces at play towards the foundation, are displayed. In short, the main structural principles of the design are depicted in this part, in order to explain the fundamental differences or similarities with static buildings.

Costs
This part covers the qualitative part of the costs. How do the materials and parts used in the project influence the costs? Most importantly, the arguments behind cost influencing decisions are covered.

(1) 3D software packages - There are several different types of software packages ranging from construction technical programs to 3D animation software. This selection of software programs is the most common used in the architectural field of work. (2) Stereolithography - A fluid is polymerized with the use of a laser. (3) Fused deposition modelling - Building up a 3D model layer by layer. (4) Laminated modelling - Physical cutthroughs of the 3D model glued together. (5) Selective laser sintering - The fusing together of a material powder in order to create a 3D model.
CORE CONTENT
Prototype

Features & functions
The prototype is a simplified scale model representing the core functionalities of the actual system. The most important features are the elements, the actuators, and the added hard- and software.

The prototype reacts to the amount of light and to being touched. The elements guarantee the necessary degrees of freedom for the prototype to move and interact.

The elements
These 3D-modelled and 3D-printed elements of the prototype represent the actual structural elements. However, the design decisions underlying these elements are also strongly based on the CAD and CAM process in order to physically build and test the concepts.

The first element was based on the geometric form of the pyramid due to the input of the preliminary research. Structural engineering arguments have led to the elimination of material in certain areas of this basic shape. The resulting pyramid shaped wire model formed the basis for further examination and modelling.

Photographs of the final parts of the prototype
The following images show several different types of the element that has developed in. The accompanying text explains the design decisions and to what extent they are based on:

- **The basic pyramid shaped wire model of the element.** The excess of material has been eliminated in order to form a lightweight basis for either the prototype as the system.

- **A combination of elements forming a possible facade arrangement.** This model has been analysed in the vertical as well as in the horizontal direction.

- **An adjustment of the system; the elements have been mirrored across the X-Z-plane in order to support its own weight and external forces from both sides.**

- **A new method of combining the inner and outer elements of the system to provide a stable structure while maintaining enough degrees of freedom.**

- **Some intersecting parts of the elements in the system have been eliminated to provide more room for movement.**

- **All intersecting parts of the elements in the system have been eliminated to provide maximum room for movement.**

- **A rotation in the 3D space of the elements to check the performance and direction of the forces.**

- **The resulting element of the system after adding a necessary amount of material to a critical part.**
Architectural decisions have led to adjustments of the shape and proportions of the complete element to erase the locally odd shape.

The fundamental new element shape combined in a system to check the performance.

A combination of the adjusted elements forming a possible facade arrangement. This model has been analysed in the vertical as well as in the horizontal direction.

The performance of only the upper (outer) part of the system was checked with this model.

A different method of connecting the elements was tested with this model.

Minor adjustments of the element itself regarding the finite elements method, material efficiency and the architectural shape and proportions.

The first possible functional model of the prototype incorporating the necessary hinges; completely shaped towards the CAM demands of the stereolithography method.

To avoid printing an expensive and non-working model only a combination of two elements with the hinges has been created for the CAM process.

A backup model when the material used in the CAM process proved to be too much weakened.

A small mounting surface for the sensor has been added as well as holes for the wiring of the hardware.

The complete and working system of the prototype with the incorporated actuators in order to check the clearance whilst functioning.

The final printed prototype: the holes for the wiring and the top triangle covering the sensor surface have been deleted to decrease the complexity of the final mesh.
The actuators

The 3D printed elements combined into element groups form the passive basis of the prototype. The system only allows it to be moved while it can not move by itself. This is the reason for the actuators to take part in the prototype.

The necessary movement of the prototype is limited per element. However a whole facade of these limited moving elements can perform quite large deviations. The actuators therefore have to provide a linear but relatively limited movement capability.

Commerically available actuators used in scale models like the prototype proved to be very expensive. It was thus necessary to model the actuators myself while the CAD and CAM process already proved to be useful and relatively cheap. Although the possibilities and expected functionality of these actuators, a low-budget back-up plan was also necessary; servos. The downside of using these is the fact that they do not represent the actual type of actuation needed in the construction system represented by the prototype.

The designed linear actuators consist of two 3D printed parts, an electrical motor, and two gears. The 3D printed parts together form a closed casing for the active parts. In one side of the casing the K10WA micro-electro motor fits neatly. The other side functions as a top lid closing the actuator off.

The elements together with the actuators form a system in need of a control mechanism. And, as the earlier chapters pointed, a certain degree of intelligent behavior of this control mechanism is necessary.

The hardware, actuators and sensors, need some intermediate to be able to communicate with a laptop or desktop where the software is installed. This gap is closed with the help of a micro-controller. A micro-controller is small electronic device who can be connected to any laptop or desktop with a COM or USB2 cable. The micro-controller has some space to save data, is able to perform some calculations and most importantly can be used to directly connect hardware to. The micro-controller used for the prototype was one of the Arduino series.

The final prototype thus contains some actuators and a micro-controller to control its movement. The movement is then related to the prototype's environment with the use of sensors. A large range of sensors can be connected to the micro-controller, however for this project the prototype will be provided with light sensors and touch sensors. Of course, these type of sensors can later be changed when one wants to examine the functionality of the prototype in more detail.

To summarize; the movement of the actuators is controlled by the Arduino Deumilanova microcontroller. The actual movement is related to input received from LDR light sensors and touch sensitive sensors based on capacitance.

(1) K10WA - An extremely small electric motor powered with 3V (2) Arduino series - The Arduino series is a series of micro-controllers; from small wearable micro-controllers to larger multitasking printboards. These micro-controllers are intensively used by prototypers because of their low-tech and easy to program character.
*Top:* Renderings of the bottom and top part of the actuator; in this part the micro-electro motor and the gears will be positioned together.

*Below:* The K10WA micro-electro motor used for the actuators.

*Top:* The position of the actuators in one of the earlier versions of the prototype.

*Below:* The Arduino micro-controller in action.
Hardware
The hardware scheme can be divided into three areas: one actuator area, one LDR area and one touch sensors area. The °nX" displays the number of times the area of a hardware connection type is used in the prototype; instead of drawing nX times the same connection.

The actuator area
The prototype relies on the controlled movement of actuators. Due to the possible failure of one type of actuator two types have been developed simultaneously. Therefore, the scheme contains two different types of actuator areas.

The servo connection is the most simple hardware connection. From the servo a power wire, a ground wire and a signal wire are directly connected to the Arduino micro-controller. In case of the micro-electro motor a more complex connection has been developed, because the electric motor cannot rotate in both directions by itself. The type of connection used here is a frequent used H-bridge.

The prototype has 3 actuators attached in order to be able to move across the three necessary axis.

The LDR area
The LDR, Light Dependant Resistor, is connected to a small resistor and an analog input pin on the Arduino micro-controller. The resistor functions as a stabilizer for the closed circuit while the LDR inputs a constant stream of analog data to the micro-controller. This data is received as a number varying between 100 and 1400. The more light the LDR receives the lower its resistance and the higher its number. The LDR’s are combined into a triangular setup. With this setup there is always one LDR closest to the light source. As a result, the software sends a signal to the actuators to position the other two LDR’s as close to the light source as possible.

The touch area
The home made touch sensor is based on the principle of electric capacitance. When a conductive volume or area is exposed to a current it buffers a small capacity of current before conducting the current any further. This behavior is used with the often used electronic parts called capacitors. Practically they are able to eliminates peaks of current through their buffering capacity.

When a piece of aluminium foil is attached to a conductive wire and a high resistor, the foil buffers a small amount of current. When the foil is touched it releases the buffered amount; the touch acts as a ground. This drop in voltage, or buffer, can be registered by the connected micro-controller. The higher the resistor, the higher the voltage difference and the more sensitive the aluminium foil will become to a ground function. For resistors at around 1MOhm the micro-controller registers a voltage drop only at an actual “being touched” state. For resistors at around 15MOhm the micro-controller already registers a voltage drop when a ground object approaches the foil at around 8 centimeters. Either the resistor or the software can be used to calibrate the necessary sensitivity.

(1) H-Bridge - This hardware connection type is designed in order to switch the polarity of the incoming wires of a connected electro motor; making it possible to rotate the electro motor in both ways. This connection consists of 4 NPN-gates connected with their signal wire to a micro-controller. When signalled in one direction, 2 NPN-gates allow a current to run from an external power source to the electro motor while the other gates remain closed and function indirectly as ground. When signalled into the other direction the system functions vice versa and thus allowing a current into the opposite direction.

The set-up for the servo in combination with an home-made touch sensor of thin aluminium foil.
The hardware connection scheme displaying the several hardware areas.
Software
The hardware of the prototype forms the physical infrastructure necessary for the software to actually "make things happen." The software can be divided into separate sections for the micro-controllers' programming environment and into separate parts controlling the accompanying hardware.

There are three sections in the micro-controllers' programming software in order to define the different sequential steps and commands the program must follow.

Section 1: Integer definition
The first section contains all the integer definitions needed for the following sections and does not need a predefined opening or closing statement for the software to run properly. This section is only run once before the following sections of the program commence.

Section 2: Void setup
The second section is called the setup. In this section it is possible to define the states of the used connection pins. For example if connection pin 4 is used on the Arduino to send signals to an attached servo it is necessary to define pin 4 as an "output" pin. If connection pin 4 is used to collect data from an LDR it is necessary to define pin 4 as "input". This section is also run once before the looping section starts.

Section 3: Void loop
The last section contains, in case of the prototype, the behavior. In this part things like for example "if touched, retreat and slowly regain your original position" are transcribed to software code. This section keeps repeating its parts of program while connected.

The behavior of the prototype has been determined and translated to a scheme. This scheme was then transcribed into the software code for the Arduino.

Code blocks
The software scheme explains which sections of software code do what. The following code blocks contain the actual code for the interested.

**Section 1**

```c
//encorporate servo puls script
#include <Servo.h>
Servo S1;
//proto 1 160 degree
Servo S2;
//proto 2 150 degree
Servo S3;
//proto 3 160 degree
int myLDR1 = 0;
//proto a
int myLDR2 = 0;
//proto b
int myLDR3 = 0;
//proto c
int a;
int b;
int c;
int d;
int e;
int f;
int i;
int j = 0;
int rate = 1;
```

**Section 2**

```c
void setup()
{
  //servo connection analog ports
  S1.attach(14);
  S2.attach(15);
  S3.attach(16);

  //communication port setup
  Serial.begin(9600);

  //touch sensor A digital
  pinMode(8, OUTPUT);
  pinMode(9, INPUT);
  digitalWrite(9, LOW);
  digitalWrite(8, LOW);

  //touch sensor B digital
  pinMode(7, OUTPUT);
  pinMode(6, INPUT);
  digitalWrite(7, LOW);
  digitalWrite(6, LOW);

  //touch sensor C digital
  pinMode(12, OUTPUT);
  pinMode(11, INPUT);
  digitalWrite(12, LOW);
  digitalWrite(11, LOW);

  //LDR sensors analog
  pinMode(2, OUTPUT);
  pinMode(3, OUTPUT);
  pinMode(4, OUTPUT);
  digitalWrite(2, HIGH);
```

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The Arduino software code scheme for the prototype; the actual Arduino software code is summarized into schematic blocks depicting the task of the accompanying code.
Section 3

void loop()
{
  /*
  // servo rest position
  S1.write(10);
  S2.write(10);
  S3.write(160);
  delay(100);
  */
  a = 0;
  b = 0;
  c = 0;
  d = 0;
  e = 0;
  f = 0;

  // light sensor reading
  myLDR1 = analogRead(3);
  myLDR2 = analogRead(4);
  myLDR3 = analogRead(5);

  // light sensor delay loop
  if (j < 3)
  {
    j++;
  }
  else
  {
    j = 0;
  }

  // light sensor measurement & action
  if (j == 2)
  {
    if (myLDR1 < myLDR2 * rate &&
        myLDR1 < myLDR3 * rate)
    {
      S1.write(10);
      S2.write(10);
      S3.write(160);
      delay(100);
    }
    else if (myLDR2 < myLDR1 * rate &&
             myLDR2 < myLDR3 * rate)
    {
      S2.write(10);
      S3.write(10);
      S1.write(160);
      delay(100);
    }
    else if (myLDR3 < myLDR1 * rate &&
             myLDR3 < myLDR2 * rate)
    {
      S3.write(10);
      S2.write(155);
      delay(100);
    }
  }

  // touch sensor check A
  for (i == 0; i < 4; i++)
  {
    // LOW-to-HIGH transition
    digitalWrite(8, HIGH);
    while (digitalRead(9) != 1) {} // while the sense pin is not high
    a++;
  }
  delay(1);

  // HIGH-to-LOW transition
  digitalWrite(8, LOW);

  while (digitalRead(9) != 0) // while pin is not low
  {
    b++;
    delay(1);
  }

  // touch sensor check B
  for (i == 0; i < 4; i++)
  {
    // LOW-to-HIGH transition
    digitalWrite(7, HIGH);
    while (digitalRead(6) != 1) {}
    c++;
  }
  delay(1);

  // HIGH-to-LOW transition
  digitalWrite(7, LOW);
  while (digitalRead(6) != 0) // while pin is not low
  {
    d++;
    delay(1);
  }

  // touch sensor check C
  for (i == 0; i < 4; i++)
  {
    // LOW-to-HIGH transition
    digitalWrite(12, HIGH);
    while (digitalRead(11) != 1) {} // while the sense pin is not high
    e++;
  }
  delay(1);

  // HIGH-to-LOW transition
  digitalWrite(12, LOW);
while(digitalRead(11) != 0)
{
    f++;
    delay(1);
}

//comparison touch sensors
if (a>400 || b>400)
{
    S3.write(10);
    S2.write(10);
    S1.write(160);
    delay(3000);
}

if (c>400 || d>400)
{
    S3.write(10);
    S2.write(10);
    S1.write(155);
    delay(3000);
}

if (e>400 || f>400)
{
    S2.write(10);
    S1.write(10);
    S3.write(160);
    delay(3000);
}

delay(1);

//write integers to communication port
Serial.println(a, DEC); // raw data
- Low to High
Serial.println( " ");
Serial.println(c, DEC); // raw data
- Low to High
Serial.println( " ");
Serial.println(d, DEC); // raw data
- High to Low
Serial.println( " ");
Serial.println(e, DEC); // raw data
- High to Low
Serial.println( " ");
Serial.println(f, DEC); // raw data
- High to Low
Serial.println( " ");
Serial.println(myLDR1, DEC); // raw data - LDR 1
Serial.println( " ");
Serial.println(myLDR2, DEC); // raw data - LDR 2
Serial.println( " ");
Serial.println(myLDR3, DEC); // raw data - LDR 3
Serial.println( " ");
Serial.println( " ");
Serial.println( " ");
Overview physical prototype

PROTOTYPE

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>ELEMENT</th>
</tr>
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<tbody>
<tr>
<td>DATE</td>
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</tr>
<tr>
<td>DRAWN BY</td>
<td>T.J.M WOLTERS</td>
</tr>
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</table>
Overview physical prototype

PROTOTYPE

SUBJECT INNER ELEMENT GROUP
DATE 7 JULI 2010
SCALE SCALED TO FIT
DRAWN BY T.J.M WOLTERS
Overview physical prototype

PROTOTYPE

SUBJECT  BLOW UP CONCEPTUAL
DATE      7 JULI 2010
SCALE     SCALED TO FIT
DRAWN BY  T.J.M WOLTERS
window element

automated opener

rotational actuator

hinge

rubber sealing

frame corner piece

insulated window

window frame

PROTOTYPE

SUBJECT: BLOW UP WINDOW FRAME
DATE: 7 JULY 2010
SCALE: SCALED TO FIT
DRAWED BY: T.J.M WOLTERS
Overview physical prototype

PROTOTYPE

SUBJECT       BLOW UP ACTUATION
DATE          7 JULI 2010
SCALE         SCALED TO FIT
DRAWN BY      T.J.M WOLTERS
Overview physical prototype

PROTOTYPE

SUBJECT         BLOW UP FOUNDATION
DATE            7 JULI 2010
SCALE           SCALED TO FIT
DRAWN BY        T.J.M WOLTERS
Movement of the prototype

The prototype in its normal position

This image displays the movement freedom of the prototype on the rotational axis 1.

This image displays the movement freedom of the prototype on the rotational axis 2.
This image displays the movement freedom of the prototype on the rotational axis 3.

The movement of one element in a certain direction caused by a moving adjacent element outside this element group.

The simultaneous movement of all elements in a group caused by an actuator connected to the ring-hinge.

The prototype rotates over a certain axis in order to maximize the total light received by the LDR sensors.

In this particular case the angle from where the most light is emitted is the top left corner of the image. The prototype automatically adjusts its orientation in order to maximize the total amount of received light onto the light dependent resistors.

This behavior is the main procedure programmed.

When the direction and intensity of the incoming light changes enough, the LDR sensors and servos will reposition the elements in order to maximize the received light again.

In this particular case the angle from where the most light is emitted is the bottom right corner of the image. The prototype automatically adjusts its orientation in order to maximize the total amount of received light onto the light dependent resistors.

This behavior is the main procedure programmed.

The immediate reaction of the prototype after being touched: a quick movement towards the element being touched.

In this case, the element on the outer right hand side is touched.

This sensor state overrides the normal light tracking procedure for a given duration. After this duration the prototype resumes its normal light tracking procedure.
Movement of the prototype

In this video I demonstrate the movement freedom of the prototype in several directions.

Screen grabs from the YouTube video: "Architectural dynamic prototype video 1"

link: http://www.youtube.com/watch?v=4MWv1OBErpo&feature=related
This video demonstrates how the prototype reacts to changes in received light and to being touched. An LED torch provides the necessary change of received light.

Screen grabs from the YouTube video: "Architectural dynamic prototype video 2" link: http://www.youtube.com/watch?v=z4DgrPQPS8&feature=related
THE CASE STUDY

SUBJECT: SITUATION CASE PROJECT
DATE: 7 JULI 2010
SCALE: 1:750
DRAWN BY: T.J.M WOLTERS
THE CASE STUDY

SUBJECT: LOCATION SURROUNDING
DATE: 7 JULI 2010
SCALE: SCALED TO FIT
DRAWN BY: T.J.M WOLTERS
The case study

As depicted earlier, this case study has been put together in order to formulate more detailed conclusions and recommendations concerning the functionality, use and architecture of the prototype used in an actual architectural design and building development situation. The following chapters cover the case project design.

Location
The following considerations led to the choice of the location of "17 Septemberplein" in Eindhoven:
1. Being able to, repeatedly, visit the location in order to investigate streams of traffic, take photographs, capture video and to get an impression
2. The location must contain enough dynamics, movement, in order to transcript to input for the building (the case project design)
3. The location preferably has several possible development scenarios to assess the level of functional diversity of the case project design
4. Access to extensive and technical information concerning the location
5. The location must provide a good understanding of the reasons behind the dynamics in order to predict the changes over time.

Program of demands
The location chosen for the project currently provides accommodation to a tourist information office. However, in the several possible development scenarios, the office will be moved elsewhere. Because of this, the office and its program of demands have been incorporated in the case project design.

In short:
1. Display area 20m²
2. 2 workspots 25m²
3. Toilet
4. Pantry 10m²
5. Storage 10m²
6. Heating, cooling and ventilation
7. Low threshold access for bypassers
8. Prominent, visible positioning in the location
A video still of the chosen location for the case study

Screenshot of a flash animation displaying the dynamics on the location; from frequently used traffic directions to hardly used parts of pavement
Architecture and Interactivity
The prototype is eventually able to react and interact to a great number of things, dependant on the level of intelligence of the building; the buildings' software system combined with a number of sensors incorporated. In this particular project, the design will only interact with the sun and by passers to narrow down the complexity of adding numerous different sensors.

Interactive cladding will either track the solar movement in order to maximize the energy generated through solar panels, or react to touch.

The surface of the building is divided into 3 zones:
1. Interactive - solar movement
2. Passive
3. Interactive - touch sensitive

The top part of the building is mostly situated directly into the sun. To maximize the energy generated through the solar panels used as cladding in this part, light sensitive sensors will track the movement of the sun to automatically adjust to a perpendicular orientation of the cladding. This movement is programatically delayed in order to eliminate constant movement due to minor light changes in the direct environment.

The rotational movement of the cladding is physically limited by the underlying constructional elements.

The elements in this part do not contain any intelligence, hardware of sensors, and function as transition zone. Such zones are necessary to avoid conflicting situations in which two adjacent zones could interfere with each others' movement. It's possible to solve such a problem physically with a transitional zone, applied in this case project, or programatically.

Dynamics add an architectural possibility to a building; next to the current tools and methods architects have at their display. In order to underline the possibilities with dynamic buildings it's important for the case project design to incorporate low threshold interactivity. In this way people gain the chance to interact with such a building themselves and to eventually take a position in terms of whether they see it as a positive development or not. Therefore, the lower part of the building is provided with touch sensitive cladding. The software behind the touch sensitive cladding of the building will transcript an anxious character as reaction to being touched. In this way people interacting with the building immediately receive a reaction, a fast retraction of the touched element. Gradually through time the element regains its original position.

The elements of which the prototype consists, and the case project design in the end also, are specifically shaped. Concept of the shaped elements is the friction between the current social dynamic context and the stable static build environment. Therefore a strong, diamond-like, fragmented shape is preferred and accentuated through the dimensions of the shape.

The footprint and volume of the case project design are directly related to the adjacent environment. Three frequently used traffic routes, directly crossing the location, are used to shape the footprint. The passing "Lichttoren" sightline, starting at the station and directly providing sight to the Lichttoren, defines the maximal height.

The volume of the case project design was then shaped in between these threedimensional border lines. With the use of different sculpting methods and CAD, the final building shape erupted.

Installation
The elements are supplied with hollow triangular sections providing watercooling and -heating. The elements cladding provides the necessary insulation. The transparent surfaces are clad with smart glass to prevent extreme heating during sunny days.

Materials
The used materials should reflect some of the following characteristics:
1. Lightweight
2. Easy to prefabricate in large quantities
3. Smooth surface
4. High accuracy production (small production dimension deviations)
5. Replaceable / exchangeable over time
6. Possible connectivity / interactivity
7. High heat resistance

(1) Smart glass - Layered glass with in between a layer of controllable liquid crystals. The glass panels can automatically adjust their transparency level according to preset values.
Digital sketch of the two types of dynamics: the top part tracks the solar movement and the bottom part retreats after being touched.
Conceptual sketches concerning the shape and its relation to the input derived from the surrounding; an important issue for the case study.

The lines limiting the shape of the building.
Study models and sketches to determine the final shape of the building.
Structural engineering

The case study consists of a stable load bearing shell; the dynamic structure system of the prototype. The shell of the building consists of similar elements. The final shape of the building is constructed with these elements. To dimension the parts, elements, of the structure, it is necessary to determine the highest local load caused by internal and external forces. Using a finite elements software package like Algor, it is possible to deduce which element is the most critical to determine the minimal dimensions needed.

The shell is divided into three sections who are connected with a series of passive, non moving elements. These fitting elements take care of the necessary enclosure of the volume as well as the necessary fixed "backbone" function for the building.

The load bearing shell is placed on the foundation with a hinging steel element. The soil beneath the foundation will be excavated and replaced to directly bear the building load. The use of different type of foundation isn't desirable due to the limited space at the construction site.

The ground floor is poured on site on top of the excavated and renewed soil. Prefabricated concrete flooring isn't an option due to the freely formed footprint.

A finite elements model with a concentrated load on top of the element. The load does not result in any deformations of any kind.

The same concentrated load situation as mentioned before only with a considerable higher load. The elements' legs are slightly deformed towards two-third of their length.

Three concentrated loads at the ends of the element displays the nature of a pyramid shaped structure; the forces are evenly divided among the entire structure without any deformation as result.

The top part of the element suffering from a sideways pointing concentrated load. As a result the entire element deforms heavily but only under a very extreme load situation.

The foundation element performing under its normal load situation; a divided load concentrated through the middle of the element. The steel bottom plate shows some force concentrations.

The foundation element performing under a clockwise moment applied at the top of the element. The steel bottom plate shows somewhat the same force concentrations.

The ring hinge performing under a moment applied in the center of the attachment axis.

The ring hinge performing under an expanding axis. This effect possibly influences the movement freedom of the ball-bearings located in the center of the applied forces.
Render of a finite elements method with the software package Algor.
Costs
The biggest costs of the case study are the structural dynamic elements in combination with the intelligent installation. This facade will be much more expensive than the conventional building methods like pouring concrete or masonry. Especially in the first fase of the realisation process because there will always be unforeseen problems and hick ups during the actual construction. On the other hand the costs for the interior finishing are lower due to the fact that the inside of the element does not need any protective or esthetic finishing.

A positive effect for the costs are the energy benefits the building is able to generate, due to the possible intelligent behavior of the system. For example solar and wind energy can be generated. This results in larger initial costs but considerable lower exploita­tional costs. This is even more true if the system, the actuators, does not consume any power when in a resting or static position.

Parallel to the development of for example solid state memory disks, the initial versions of new products are extremely expensive. However, further and further down into the production period, and only when successfully admitted into the built envi­ronment, the costs will be reduced heavily. The used material and the potential quality of the prototype are the major incentives for this process.
Historical Cost of Computer Memory and Storage

Graph from SPSS depicting the almost linear descending costs.
CONCLUSION
The end
Conclusions

The process
The parallel design process used in this graduation project soon proved to be quite complex. The reason originates in the fact that numerous fundamentally different products are being created in the same period. You will have to constantly switch between for example a 3D software package, a 2D software package, a physical model and 2D sketches all with their different operating methods. On the other hand the advantage appeared to be the variety in work activity; while several days of work on the same product can become boring and eventually possibly lead to lower quality products.

Towards the end of the process the complexity in the parallel design process peaks. A great number of decisions have to be made and the number of iterations, evaluation moments, increases heavily. An advantage is the necessity to have the relation between products extremely clear. This proved to be the case because I have managed to think the influence of some of the design decisions through, for all the related products before actually applying them. In other words, some of the last iterations of the products in which decisions are to be made, can be simply thought of without changing anything before you are sure it is the right thing to do.

The parallel design process used to design a prototype is very sensitive to never reach a finishing state. Almost everything in this process can be determined important or not important by yourself as well as the product resulting from those demands. In other words, it is possible to infinitely adjust the demands to the products or the products to the demands. This is especially true towards the end of the process when a lot of learning moments and obsolete decisions ask for allocation when you also have the possibility to simply adjust the products again. This effect also arises in a normal design process only then a lot more decisions are made final and tangible, resulting in less room for changes.

CAD
A difficult issue proved to be finding the right CAD tool for the job. I have tried several different software packages including crash courses, tutorials and online lessons but none of the packages could support the complete chain in the rapid prototyping method. Finally Rhinoceros proved to be the package closest to the CAM process I chose. A good method in choosing the right software package is a bottom-up approach; what type of functionality does the prototype need and what material does it need to be build of? Where can I find those materials? What kind of file do I need to print those materials? What software package handles those files easily?

CAD and architecture can form an excellent couple; however it is very easy to lose your design target out of sight due to the visible and invisible limitations the software package you are using contains. It is very appealing and easy accessible to just find an "good enough" modelling option to reach a certain effect, but when doing so you compromise the actual target and forget the actual purpose of CAD. It is supposed to be a modelling tool, and just like any other tool you will need to use it only, and only then when it fits the job perfectly. Combined with the earlier mentioned issue of finding the right software package it is very difficult to not be influenced by the CAD system you are using. Hence the sometimes easy to recognize software package used by a person on a rendered design image.

Not having enough modelling skills is a very demotivational situation often reached with CAD. Just like ordinary craftsmen, it takes practice and patience to gain modelling skills. This is often forgotten in a CAD project but limits the quality of the actual project in a frustrating way. Theoretically innovative and unconventional projects, like this prototype project, suffer more from these problems than normal design projects. This is true because they tend to have more different and new methods than currently available in CAD. Such projects thus ask more ingenious solutions from the user to reach the goal.

CAM
Using a different CAM method results in a different prototype making the choice for CAM sensitive to compromising the prototype. Types of material, 3D printing deviations, maximum model size, necessary printing clearance and wall thickness. These are examples of different CAM conditions resulting in prototype design decision changes. This actually means that there appears to grow a difference between decisions based on what the functionality of the prototype should be and how it can be reached. The latter sometimes influences the functionality directly. CAM thus requires extensive knowledge as regards to the production method content and is therefore desirable to pre-study the CAM field of work, in order to minimize the influence on the desired functionality of the prototype.

Rapid Prototyping
It is important to quickly build a conceptual working version of the complete final prototype while there are always considerable Hick ups during production. Near the completion of the final prototype I still did not construct a complete working prototype. I did build the different necessary functionalities in
separate models, but not together as one as the final prototype should. This situation endangers the continuation of the process due to the possible newly encountered problems.

For a graduation project, rapid prototyping with the use of 3D printing methods are quite expensive. It is necessary to build several prototype versions with different actuators, sensors and materials before even building the final model. All together these parts add up a considerable bill.

Using rapid prototyping together with an architectural design process improves the realism greatly through the automatically incorporated necessity of makeability. CAM forces the designer to think the consequences through of their design decisions. The use of CAM thus reflects the actual design process more realistically than only in a CAD process.

The prototype
The shape of the building influences the degrees of freedom of the system. The elements of which the system consists of are triangular equilateral. In order to design with such elements the shape of the building itself is limited by the possibilities of these elements or, in the opposing scenario, the equilateral triangles approach the chosen shape. Either way and roughly said, the more complex and fragmented the shape, the more limited the degrees of freedom are of the elements.

The automated translation of the shape of a building into a facade consisting of the designed elements is problematic. Several mathematicians have tried to develop similar automated algorithms in order to remesh an arbitrary shape to equilateral triangles. The most promising method is to approach the original shape as much as possible with a new one divided into different segments. These segments are then connected with non-equilateral triangles.

The prototype allows behavior related to numerous different sensors attached. However, the more different types of sensors, the more complex the software, and the general behavior of the prototype in the end. When using multiple types of sensors it is extremely important to examine and determine their priority towards each other. If this is not done properly they possible overrule each other in movement, cancel each other out or keep iterating between positions.

Some elements of the system need to be fixed. Otherwise the movement of individual elements is distributed among adjacent elements resulting in random and unpredicted motion. Depending on the shape of the building, the foundation provides such a fixation.

Due to the fact that the building contains highly integrated soft- and hardware it is likely that some parts will malfunction. It is thus important in such situations, to still accommodate and provide the minimal set of demands the building needs to fulfill.

The interior of a building consisting of the dynamic system, how it functions, is very unusual. The ways and methods currently used in our buildings are not suited for such environments. Simply because too much elements decrease the possibility of movement.

The prototype does incorporate movement into a bearing structure, however the method for doing so can be perfected. The development strived to reach a combined system in which bearing forces and interactive dynamics could go hand in hand. Nonetheless the prototype still separates this movement into a passive and active part. A better method for reaching such goals is possibly found in the characteristics of the used material itself. For example the memory shape plastics.

Because the prototype is able to intelligently interact with its environment generating energy is one of the stronger points of behavior. Constantly seeking an optimal solar- or windenergy generating position for example, lies within the possibilities to do so.

Developing dynamic building systems forces to combine and overlap several fields of work. The system actually eventually reflects the quality of these combined fields. The simpler the system, the complexer the process was. For example it is possible to combine constructional strength and shape deformation into one material with which the architect is able to determine an interesting element shape. Conventionally such an element consists of a bearing structure element, hardware and software to determine the deformation, and finally an active system to apply the movement. More parts, less complexity. Dynamic buildings require intelligent engineered elements in order to be prepared for future demands.

It is possible to directly transcript demands to the functioning of the building into behavior over time. In this way a changing surrounding does not necessarily mean a loss of function or architectural concept but merely a change in form of the dynamic building. New building projects adjacent to the dynamic building can for example influence the shadows across the dynamic building. If programmed accordingly,
the building can partly change its shape to, again, gain the demanded benefits from the sun.

The building system is build up from similar elements; an existing building can thus be scaled up or down by adding or removing elements.

The case study, using the prototypes’ system, preferably does not influence the system its design. If it does, it simply means the demands and functionality of the system are not complete; the prototype thus is not suited to be used yet.

Further research
The most interesting issue is the possible combination of intelligent behavior and material. Some materials have characteristics which can be put to use in passive intelligent behavior without adding a separate installation. For example, the expansion and contraction of a material under the influence of temperature changes can be used to automatically adjust shape or orientation of elements. Such “in-built” material characteristics can be put to use as intelligent behavior of a building system.

Dynamic building systems integrating architecture, structural engineering, and building physics are more future proof if they are self-sufficient. This subject concerning the energy entity is critical for the future development of the system.
Glossary

Actuator
A device consisting of a piece of machinery that has moving parts performing some function.

Bearing
Those parts of the structure responsible of ensuring and diverting the necessary weight distribution towards the foundation.

Behavior
The actions or reactions in response to external or internal stimuli.

Byproduct
The bycoming product automatically resulting from the development of something else.

Causation
Based on the logic of prediction; predicting a certain development or situation and taking actions accordingly.

Competence
The state, quality and capability of being adequately or well qualified concerning a particular subject.

Concept
The total and combination of arguments, wishes, and demands, in such a way, that one can speak of the beginning of a piece of art.

Conventional
Conforming to established practice or accepted standards; traditional.

Dynamic
Referring to the physical dynamics, not merely tectonics, of a building, thus being able to for example alter its orientation, change its footprint size, or interact with bystanders.

Effectuation
Based on the logic of control; taking actions according to the current situation in order to maximize the current control on a situation or development.

Element
The repetitive used and most fundamentally designed part of the structure responsible for the main idiom of the total assembly.

Entrepreneurship
The act of a person, the entrepreneur, "taking endeavor" in order to reach a certain economical goal.

Environment
The combination of social, cultural, and external physical conditions that affect the built subject.

Footprint
The surface space occupied by a structure or device when placed in its final and operating position.

Fragmentated
The convergent division of what used to be a constellation.

Intelligent
Referring to the possibility of elements of the prototype to display, communicate, receive, interpret and transfer information in order to mimic parts of human natural behavior in the buildings' dynamics, with the use of actuators.

Interactive
Involving the communication or collaboration be-
tween people or thing.

Interrelated
The mutual related influences between parts or elements.

Kinetic
Related to the motion of material and physical bodies and the forces at play.

Mastertrack
A defined sphere of work within the masters degree program of a University in order to define the study and learning boundaries for a student.

Prefabricated
To manufacture a building or section of a building, in advance, especially in standard sections that can be easily shipped and assembled.

Preliminary
Prior to or preparing for the main matter, action, or business.

Prototype
A first model, mock-up, of a product, in order to evaluate the functionality for the possible future production.

Shortlist
A list of preferable items or subjects selected from a long list, for final consideration.

Supercomputer
A computer that performs at or near the currently highest operational rate possible for computers.
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<thead>
<tr>
<th>Title</th>
<th>Author/Institution</th>
<th>Year</th>
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<td><strong>Absent Bodies</strong></td>
<td>by Ignasi de Sola-Morales</td>
<td>1997</td>
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<td><strong>ADIC Future Solar Responsive Façade</strong></td>
<td>Abdulmajid Karanouh Aedas Architects</td>
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<td><strong>Elasticity- the case for elastic materials for kinetic and responsive architecture</strong></td>
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<td><strong>GameSetendMatch</strong></td>
<td>Publikatiebureau Bouwkunde</td>
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<td><strong>Hyperbodies</strong></td>
<td>by Kas Oosterhuis Hyperbody Faculty of Architecture</td>
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<td>Kas oosterhuis, Xia Xia (eds)</td>
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<td>Tony Olsson</td>
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<td>Henriette H. Bier Hyperbody Faculty of Architecture</td>
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<td><strong>Shape Control in Responsive Architecture</strong></td>
<td>by Tristan d'Este Sterk</td>
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<td>John R Amend jr. Cornell</td>
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<td>Aurelie Mosse Copenhagen</td>
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<td>by Tristan d'Este Sterk Chicago</td>
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<td>Gunnar Green, Berlijn 2005</td>
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<td>Derelict building to work of art - The moving building</td>
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<td>Prototype of my dynamic proximity model</td>
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<td>The Future of the skyscraper</td>
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PROTOTYPE OF A DYNAMIC BUILDING

Our built environment displays a major and possible unwanted difference towards the society dwelling within; the built environment is static and steady while our society is dynamic and unsettled, changing constantly at an almost endless seemingly exponential perspective. Innovative structural engineered buildings carry the potential to take this gap away, through reflecting the dynamics present in our society, a dynamic building. To successfully keep up with the constant changing environment it is necessary for such a building, to be able to interact and behave intelligent during the exploitation period. Both main issues, a dynamically structured building and intelligent behavior, have been investigated through the development of a physical prototype.

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Author T.J.M. Wolters

Graduation report
Mastertracks Architecture & Design Decision Support Systems
University of Technology Eindhoven
Faculty of Architecture Building and Planning

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