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Temporary, easily removable structures

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KEYWORDS
Temporary, easily removable and mobile membrane structures

ABSTRACT
Traditionally, membrane structures are used for weather protection during open-air festivities. In these occasions, it is very common to use standard rental tents. These rental tents are designed without any relation to a certain location. For unique locations, such as places of cultural historical importance and which are regularly used for festivities, temporary removable structures are an interesting alternative. This has both architectural and technical advantages. For example, the design can interact with the unique character of the location. From a technical point of view this gives the possibility of permanent foundations. In the past years Tentech developed a new approach for easily removable or semi-demountable structures. On the basis of three case studies (figs 1 and 2) this approach will be discussed. In this discussion aspects and considerations like: structural safety and load cases during erection and utilisation, degree and way of divisibility, connection detailing, materialisation and restriction of assembly time will be discussed.

Figure 1 Open-air Theatre, Soest (NL).

2 Soest Open-air Theater

The first project in which a temporary structure became seriously in question was for a stage covering of the open-air theatre in Soest (the Netherlands) (fig 1). The location of the open-air theatre is of ecological importance and is part of a national system of connected nature reserves. Therefore permanent buildings were not allowed and even some existing buildings were removed. The expensive agricultural land was given back to nature. Under these circumstances our client, a local government, had to handle carefully. A permanent structure would have lead to resistance, while a
Temporary, easily removable structures, Rogier Houtman and Harmen Werkman

The design of the Soest tent lead to a new project: a square covering for the Nedap company in Groenlo (the Netherlands) (fig 2). On the square in front of the company’s head quarter the management board wanted a simple-to-erect structure for diverse performances. The square covering is positioned in front of the entrance façade. In this way a closed area is created for public and performances. The design of the structure is in many ways a continuation of the Soest concept. In this project the idea of using permanent columns for hoisting the membrane structure into position is worked out in detail. Because Nedap has the disposal of a technical staff it was not hard to form a appropriate crew for assembling the structure. Starting points for the engineering were a crew-size of 2-3 persons and an maximum assembly time of 4 hours. From an architectural point of view the client worked with high standards towards detailing and material usage.

Figure 1 Temporary square covering, Groenlo.

Although in an architectural point of view a satisfactorily result was reached, it was not simple to integrate hoisting facilities into the masts sections. Besides that the client wanted slender columns without any protrusions or additional elements. Hoisting facilities had either to be fully integrated inside the masts or to be totally dismountable if they would have been placed outside. Here is was chosen to place the hoisting system outside the masts so they are removable. This does not improve the speed of the installation process and asks for special attention of the crew. Nevertheless the size of this structure is small and it is possible to erect it within 4 hours with 4 people (employees of the company, who know how the system works).

3 Temporary Square Covering Franeker

As part of the redevelopment of the town centre of Franeker a semi-permanent square covering was planned. The structure provides for weather protection during several open-air events during the
whole year. Architect Klaas Klamer designed a tensile structure which emphasizes the diagonal of the rectangular square. In this way a route between the two important shopping streets is created (fig 3). The main axis is almost 35 metres long, in perpendicular direction the structures measures 25 metres.

The membrane roof is supported by two permanent columns on the diagonal axis and six dismountable edge poles aside. Permanent guying cables were not allowed, therefore the two columns are moment resistant connected to the foundation. Only when the membrane is present the columns are supported by cables for additional stability. This means different deformation behaviour in both cases. Therefore a lighting structure, which is suspended between the columns, is connected by a specially designed spring system. In both cases this spring connection provides for sufficient tensioning in the suspension cables.

Part of the engineering task of Tentech was to provide a simple assembly procedure. A small crew of volunteers has to take care of the assembly. Therefore a simple and fast erection procedure is developed. The first phase of this procedure is to lay out and connect all dismountable elements on ground level. Because of the weight restrictions and easily handling the membrane is divided into two parts which can be connected easily by a structural zip. The same reasons lead to the appliance of fibre reinforcement of a synthetical material instead of steel. In this case Vectran fibres are used in a polyester hull. These belts which measure 4 x 50 mm in section can withstand forces up to 135 kN. Because the forces in the main cable reaches almost 400 kN several belts are combined in a structural way.

In the next phase the whole structure will be lifted up to its definite height (15 metres). Therefore the main cable of the membrane structure is connected to hoisting rings which are fixed around the main columns. Hoisting rings and complete structure (including the guying cables of the main columns) are lifted up by wire rope hoists which are integrated in de basements of the main columns. The system will be secured when the hoisting rings has reached ultimate height. Onwards then the main columns are guyed for additional stability and a safe situation is reached for (pre)tensioning the membrane.

In the third and last phase the membrane is tensioned in peripheral direction by using the edge poles. By pulling these masts in peripheral direction the membrane is (pre) tensioned. Because of large forces special equipment like fork-lift trucks or Tirfors are necessary. During this operation ball joints in the masts ensure sufficient freedom in movement. Once in position the guying cables have to attached and when necessary tensioned. Because the complete structure is adjusted during the first assembly, adjustments are not necessary during next assemblies.

By using the procedure mentioned above it is possible to erect the membrane structure in almost four hours by a crew of six people. Until now, the structures of almost 660 m² is built for two times. In these periods it withstands both strong wind loading and snow loads and it behaved even in these circumstances quiet well. Light and acoustic conditions are well and by adding special designed walls nice spaces are created underneath the covering. The spaces which will provide a shelter to many open-air events in the historical town of Franeker.

Figure 3 Temporary square covering, Franeker.
Walking Shelter

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KEYWORDS
Adaptable, Pneumatic, Robotic, Lightweight, Structure.

ABSTRACT
This presentation addresses issues concerning the development of pneumatically adaptable structures, in particular semi-autonomous shelters. The work described is being carried out in order to investigate the feasibility of combining a variety of relevant technological concepts. Although the resulting building configurations appear complex and high-tech, it must be stressed that most of the individual components utilise well understood and, in many ways, mainstream engineering. The fundamental concepts underpinning adaptable pneumatic structures have been proposed and understood for decades. The fact that the construction industry has until now not been more active in using these ideas has been mainly due to high costs and low reliability. Today we are beginning to see the adoption of complex pneumatic structural components in practical, as opposed to expositional or research structures. Given the many performance advantages of pneumatic structures, as well as the exciting architectural possibilities they offer, it seems probable we are on the verge of an interesting period of development and realisation.

Recent experiments have been directed towards the development of a pneumatic shelter capable of walking from location to location. At its simplest, the concept is essentially a hybridisation of a deployable arched airbeam shelter, with a classic insectoid walking robot. The objective is ostensibly practical, but the main purpose is to investigate the combination of particular pneumatic components in an adaptable architectural structure.

Figure 1. Walking robot + Airbeam tent = Walking Shelter
A concept in industrial building and custom-built houses

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KEYWORDS

industrialized building, housing, residential construction.

ABSTRACT

The main principle of the way we build houses today shows a striking similarity with construction already known in Ancient Rome [Lamprecht 1996]. The numerous improvements that have been made during the last decades (regarding insulation, fittings and finishing) are basically added to the initial Roman practice of construction. The result of this is that technique, as well as process, as well as organization in residential construction is become deformed after a succession of additions, making present residential construction very inefficient and inertial [Lichtenberg 2005]. A radical reverse of residential construction is essential with emphasis put on real industrialization of large building parts. This paper describes a conceptual idea for industrializing residential construction that is specially geared to enable unique design results. This principle called industrialized building, sets up facilities for an industrial way of building. It aims to combine most benefits of industrialization (regarding quality, cost-effectiveness, labour condition, et cetera) with prefabrication (to adjust elements enabling unique results) and traditional work (to construct on different locations with site conditions far from ideal), all as essential ingredients of industrial building. The result will be an open way of building enabling special requests, crucial for creating unique complex building projects.

1 Introduction: industrial building versus industrial production

Industrialization in residential construction asks for a special approach since this market is quite distinct from well-known industrial markets for its scale (and subsequent complexity), its fragmented opaque organization, its implicitness of unique design results and the major influence of specific site conditions. This might explain why all closed systems have failed on a large-scale until now, leaving industrial building nowadays with a smack of uniformity, dullness and artificial embellishment. Urban developers / architects want an open building system to get attractive residential environments that give a certain individuality and identity to its residents. Tradition to anticipate on unique results has always been a distinctive characteristic of building. Architectural designers are trained to this. But also for principals this is something that goes without saying. A client seeking an architect who submits a plan from a cupboard will be disappointed before all else and will secondary ask for excessive modifications. There are a few companies that offer catalogue homes, but in practice a catalogue model is as a rule a starting object to be shaped by multiple drastic modifications. The often-made comparison of industrial building and car industry (or consumer goods) won’t stand up because of drastic modifications that are taken for granted in residential construction.
Yet modifications are not only desirable to provide identity or individuality to the owner-occupier. In most cases specific site requirements dictate main modifications. Especially in crowded regions as the Netherlands one cannot go on creating new suburbs so building capacity will focus more and more on existing sites to be built over. Historical set infill and refill projects require a flexible way of building since housing that is closely fit in (as in city centres, fig. 1) can bring more attractive housing conditions than fragmented infill based on standard components.

Figure 1. Infill and refill projects in city centres will become more important in future construction requiring an adequate construction principle that enables tailor-made housing.

Closed industrial building systems fail in the long run. It would also be bad policy to develop a new system of industrial parts just replacing existing parts since current construction is already inefficient and inertial as a result of successions of innovations by additions [Lichtenberg 2005]. An approach of replacing would likely settle new additions or substitutions, blocking improvements of efficiency. Instead a novel open system based on industrial parts with simple options to make explicit houses will bring in a real chance of substantially improving the overall efficiency as indicated by the example in this paper [Moonen 2006].

2 Industrial versus prefabrication

The open industrial building method will be based on real industrialization. With real industrialization is meant that the greater part of a building section is mass-produced in an automated process on specification of the manufacturer. This in contrast with prefabrication where parts are produced off-side based on requests of clients. Since prefabrication mostly goes with rather small series of identical parts benefits are moderate compared to real industrial production (yet quit large compared to work on-site). A meaningful distinction of industrial production vs. prefabrication is essential in this paper however building industry in general fails to see this distinction by treating both terms synonymous.

Figure 2. Examples of off-site production. Prefabrication profits compared to traditional on-site construction, although many activities still bear resemblance with working on-site.

Figure 2 shows typical prefabrication in a workshop. Since dimensions and details differ per element production often incorporates a large amount of traditional skills. A salient feature is that almost the same parts (and details) are used as if the panel would have been constructed on-site. The numerous small elements with often different preparations make manufacturing quite difficult to industrialize.
If activities in a workshop would have been reduced to connect (and accidentally adjust) large parts, prefabrication would be faster with likely more opportunities to optimize. The challenge is to develop mass-produced parts that incorporate many functions and activities to minimize workshop actions but still enable same (or even more) flexibility in utilization. Preliminary studies of wall, floor, roofing and foundation indicate that this concept, called industrialized building, can result in a serviceable and profitable open building method [Moonen 2004].

3 Industrial with prefabrication: Industrialized-building

The underlying assumption of industrialized building is that one should always distinguish three consecutive stages when developing a building component (Fig. 3):

- **automatic production** of parts (fully mass-produced to benefit bulk-production / prepared to enable adaptations and combinations in the next phase / large-sized with ingenious facilities for all kinds of applications and installations);
- **built into** an unique whole (in a workshop) obtaining large prefabricated composites by adjusting and combining (different) mass-produced parts (composite is processed by project requirements);
- **mounted** on site (of large components enabling fast assembly with simple connections).

In developing one can optimize industrialized building by shifting as many activities as possible to a higher level in the scheme. The aim is to allocate at least 75% of costs of a building composite to the industrial stage. Industrialized building focuses on large components to transform construction on site into assembly on site.

![Figure 3. Scheme of industrialized building that distinguishes industrial, prefabricated and traditional activities, all as essential features of modern building. In developing one can optimize by shifting as many activities as possible to a preceding level.](image)

Of course there are all kinds of intermediate versions of industrialization and prefabrication that can and will be used when parts and composites are finally produced. However in developing it does serve to make an explicit distinction of parts that are produced without specifications of clients (thus that can be combined, easily automated and stocked) and components that need specific input from a final user. The distinction also enables to quantify industrialization enabling further improvements. Although the first impression of Fig. 3 is one of insignificant linguistic quibbling, the example of industrialized foundation [Moonen 2006] shows that it does make a substantial distinction.

Figure 2 shows that building components (such as floor elements) are nowadays developed as scheme (enabling variation of length, composition and provisions). If one would consider the same floor composed out of mass-produced parts with incorporated composite functions (compare a chessboard with the outer parts made to length) the workshop could make a complete other spectacle.
4 Industrialized foundation

The concept of industrialized building is explored and tried out in developing a foundation. This novel foundation is explicated in proceedings [Moonen 2005, 2006]. Essentials of this foundation are 3D-shells of Expanded PolyStyrene (EPS) used as permanent formwork and a swapped sequence in construction (refill soil before mortar is poured enabling simultaneous pouring of ground floor and foundation). The 3D shells incorporate different functions such as reducing materials, fixing reinforcement, allowing sewage pipes to pass without extra activities, stiffness during transportation, upright partition during pouring of floor, lowest insulation in cavity, enabling coupling of 2-4 prefabricated components at any angle, etc. These 3D-shells can be mass-produced and suit for strip foundations as well as pile foundations. Also a base reinforcing cage can be mass-produced. Next, several 3D-shells and a reinforcement cage are assembled in a workshop to make a foundation component. Assembling starts after receiving the definitive project requirements. Extra activities in the workshop are cutting of some 3D-shells to a required length, lengthen reinforcement cages and than cutting to required length, adding extra reinforcement bars if necessary. In this way all parts of a foundation layout are prefabricated making the complete formwork a kind of ready-to-construct kit. These prefabricated components are transported to site where an excavator will dig them in. After all groundwork is finished (including preparing the ground floor) concrete mortar is poured on top of the ground floor en so filling the foundation beams [Moonen 2006].

![Image](image.jpg)

Figure 4. Photos of a pilot project of the industrialized foundation showing the main activities.

The industrialized foundation is tested in several pilot projects (Fig. 4). Also a feasibility study has been made based on results of pilot projects, including an estimation of costs [Koolen 2005]. Also the allocation of costs to the three stages (industrial – prefabricated – traditional) is unravelled. Here it is found that mass-produced parts add 77% to the overall costs while activities on site are reduced to 18%. Interesting is also to observe that prefabrication contributes just 5% in the overall cost. This emphasizes the presupposition that making unique layouts based on mass-produced parts is feasible at quite moderate costs.

Other found advantages are: reduction of on-site labour (45%), reduction of materials (30%), reduced overall building-time and reduced costs (30-50%) compared to traditional substructures (Fig. 5).
Figure 5. Outcome of feasibility study. When compared to traditional strip foundations costs are about halved by omitting brickwork (left) or by reducing concrete (middle) [Koolen 2005].

5 Conclusions

The principle of industrialized building sets up facilities for industrializing residential construction with emphasis put on retaining the possibility of creating unique houses. Industrialized building is based on distinguishing industrialization, prefabrication as well as handcraft all as essential ingredients of producing a building composite. In this it aims to combine benefits of industrialization (regarding quality, cost-effectiveness, labour condition, etcetera) with benefits of prefabrication (to adjust elements enabling unique results) with minimal traditional work (required since construction is on different locations with site conditions far from ideal). The result will be an open way of building enabling special requests, crucial for creating unique sustainable building projects.

The aim of industrialized building is to have mass-production to contribute at least 75% of the total costs of a building component, leaving maximum 20% for on-site construction.

The principle is preliminary studied for wall, floor and roof components. Also a novel foundation is developed based upon the principles of industrialized building. Significant advantages (such as 45% reduction of on-site labour, 30% reduction of material, substantially reduced overall building-time and 30-50% reduced costs compared to traditional substrucures) confirm the potential of this approach of industrialization in residential construction.

6 References

Antoni Gaudi: a pioneer in Structural Morphology

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KEYWORDS

Funicular shapes, catenaries, polyhedra, curved surfaces, natural systems

ABSTRACT

1 Introduction

It is a matter of fact that Antoni Gaudi is one of the most surprising architects at the beginning of the twentieth century. “Was the Sagrada Familia the last cathedral? ” asked a journalist. “No this is the first of a new type” replied Gaudi. And effectively Gaudi was always thinking with some decades of advance, he was not a nostalgic of past architecture. We can find in his constructions almost all the actual tools of structural morphology except, of course, computer modelisation.

Several aspects will be developed in this communication, some are related to shape, some are related to mechanical behaviour.

2 Nature as support of imagination

Double curved surfaces can be found in nature. The examples of trees shown in an exhibition in Barcelona can be related to paraboloid hyperbolic shapes and these ruled surfaces are realised with an exceptional virtuosity by catalan builders, who were expert in flat bricks building.

Gaudi observed that in nature the cross section of some branches do not keep the same shape all along the mean fibre: their form can be triangular at one end, and hexagonal at the other. Taking advantage of this observation Gaudi decided to modify the cross section of the Sagrada’s columns beginning with a circle to end with a cross section with four squares, which give birth to four new branches whose cross sections shapes evolute from these squares to circles.

Figure 1. Tree like branching of columns and transformation of the cross section from circle to squares, and from squares to circles
3 Polyhedral geometry

Gaudi was also expert in the knowledge of polyhedra, as plaster models of his own can assess. The upper part of the towers in Sagrada Familia use extensively the polyedric geometry.

One specific polyhedron was used for the pinnacle of the Nativity façade of Sagrada Familia. Its generation has been clearly explained by Claudi Alsina [2002], whose explanations will be described.

Figure 2 Polyhedron plaster model for pinnacles.

4 Reverse hanging method

Structural morphology, whatever can be the definition according to personal views, always implies the coupling between form and forces, between geometry and mechanics, between visible and invisible. Gaudi was certainly not the first to use the so called “reverse hanging method”; before him Poleny used it for a study concerning the Pantheon, and after him Einz Isler was very famous in the field of concrete shell form finding by using this technique, but all builders know the exceptional understanding of this experimental form finding method, exemplified by the Colonia Güell near Barcelona, with its inclined columns.

Figure 3 Hanging model for Sagrada Familia

We will explain this form finding method and give many examples of its use by Gaudi in several works.

5 Acknowledgments

My interest for Gaudi is certainly related to his pioneering studies in the field of structural morphology, but I had the chance to meet recently Jan Molema, expert in the knowledge of Gaudi [1987], and Jordi Fauli, always working in Barcelona in the direct spirit of the Catalan architect [2005]. We could together organize in Montpellier an exhibition and some conferences in 2004 [2004]. It is my pleasure to thank them warmly, since this paper can only be considered as my willingness to share with them and the readers my respect for this pioneer.

6 References

Heat adapting membrane

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KEYWORDS
Climatic membrane, cooling, heating of tensile-structures, igloo

ABSTRACT

1 Textile radiator
The most usual way for cooling a tensile structure is by using different layers. The air between the layers is used as an isolating material. When the air in between the layers has become too warm, it can be ventilated away. Another way is the use of a phase changing material in the membrane. In a moderate climate this will be sufficient. When a higher capacity is required, the temperature problems of tensile structures are solved by heating or cooling air. Conditioning a tensile structure in this way is not as efficient as by the use of a radiation surface. Therefore we developed a textile radiator that is capable of adapting 500W/m2.

2 Igloos
This research started with the making of an igloo in summer. For the construction of this igloo ducts were winded around an inflatable mould to get a grid with an average distance of 5 cm between the tubes. In total 2000 meters of ducts were used to cover the whole inflatable mould. This work took 3 days by 5 people. (Fig 1) After the ducts had been winded around the inflatable mould water was sprayed over the ducts. It took 3 days to get a layer of ice thick enough for a stable ice structure (10 cm) (Fig 2). The interior of the igloo was sprayed with water 1 more day after the inflatable mould had been removed. (Fig 3).

Fig 1       Fig 2        Fig 3
The igloo was a big success. Unfortunately it was too much work to make it feasible for expositions. Therefore we researched a heat-adapting membrane with a high capacity.

### 3 Heat adapting membrane

The heat adapting membrane is based on the principle of vacuum injection. Vacuum injection is a method to inject resin in a fabric. First a fabric is placed in a mould. After closing the mould a pressure differential is applied that impregnates the fabric with resin. The pressure differential of vacuum injection technique is obtained by means of a vacuum. The technique is used to impregnate a fabric with a thermoset resin. The injection has to take place within the cure time of a resin. To make a heat-adapting membrane the water has taken the place of the resin. The volume between the two layers is brought to under-pressure. To keep a space between the layers a drainage material is used (Fig 4). Through this space it is possible to transport water. When glycol is added to the water, the water can be cooled. In this way it is possible to make ice on the surface of the membrane.

#### Fig 4

In a modification of the system the cooling glycol runs through tubes in the drainage material. When the water between the two layers becomes ice, a stable sandwich structure is formed. By spraying the sandwich it is possible to have an icy surface (Fig 5).

#### Fig 5

### 3 Conclusions

Distance fabric is known for the application of transport and storage of air and water. It can only be used in a flat surface. With the described system it is possible to make a curved double-layered systems with the capacity of transporting air and liquid. The developed system is capable to heat or cool tensile structures with a low energy system. In combination with heat storage it is possible to use the system for cooling during the day and heating in the night. Especially for a desert climate with a big difference in temperature between day and night this way of controlling the temperature will give an environment-friendly solution.
GEK – Touring exhibition

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KEYWORDS
Pneumatic modules for travelling exhibition.

ABSTRACT
On the occasion of the 125. anniversary of the Gmünder Ersatzkasse a touring exhibition was planed, travelling to 29 towns all over Germany. Meanwhile this exhibition has been extended to the end of 2006, and to more than 80 locations. In the different towns the exhibition is assembled inside hired halls.

The exhibition represents a walk through the human organism with heart, lungs, skin and a lot more. Basic idea of the design was a modular concept consisting of rooms and hallways. The cover should be organically shaped which led to a pneumatic solution.

0.1 Heart chamber; 2 kinds of hallways

1 Design
The shape of the structure differs clearly from the conventional pneumatic structures. Therefore an active influence on the formfinding was necessary which meant to more or less predefine the form in many partitions.
The exhibition has to be adapted to the situations in the different towns, therefore all hallways and rooms can be connected to each other in any combination. At the junction between room and hallway a joint detail with a determined perimeter for all junctions was developed. The junctions were executed as french lacing, with cover bands off membrane material.

2 Entrance and exit airlocks

During the design it became obvious that standard solutions were out of the question. Together with the membrane manufacturer and the architect we developed a pneumatic airlock through which the visitors have to press themselves to get inside. Two air chambers press against each other and close the entrance and exit. The pressure inside the chambers was selected in a way that the visitor can pass through with as less effort as possible and the joint still is tight enough to minimise the air leakage. Steel arches on the outside keep the airlocks in shape. For persons in wheel chairs and for push chairs the air is sucked out of the cushions and the opening is free for a few seconds. The opening time has to be kept as short as possible to minimize the decrease of pressure.

2.1 Airlock

2.2 Inflation process
ETF-Foil, the "flexible glass".
An alternative to glass roofs!? 

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KEYWORDS
ETFE-foil; Textile Architecture; Pneumatic structures; Lightweight structures, Tensioned structures.

ABSTRACT
Lightweight structures have been established in almost all fields of construction within the last 30 years. The use of tensioned structures with their three dimensional shapes in combination with all known building materials (like steel, wood, concrete and not to forget ropes) allows to either adapt architectural elements to break up solid buildings or to form complete buildings or coverings itself. Mainly you will find textile architecture in the field of leisure and sport and around all public places.

For sure a spectacular event was the soccer world championship within the last weeks, where the spectators have been protected against the weather conditions by textile roofs.

So far lightweight structures are known as structures made out of coated fabric, either PVC-coated PES weaving or PTFE-coated glass weaving. The weaving inside these materials is what we need to carry the load out of the pretension. The coating itself is “just” to protect the weaving against weather conditions and maybe to bring colour into the structure.

The pretension is adapted by mechanically. Beside that a lot of pneumatic structures have been built within the last years, starting with simple air supported halls up to huge pneumatic cushion constructions. In all this projects the membrane is tensioned by air pressure. Compared with high pressure elements like a tire of a bicycle or a car, textile structures require a low pressure only due to the volume of the structures. So for example the inner pressure of the large cushion of the German pavilion in Seville ‘Fig. 1’ with its 90 x 65 m free span was 1000 Pascal only.

Pneumatic structures opened the possibility, to use other materials than coated fabrics for “textile architecture”. Especially the use of ETFE-foils has become very common within the last years. ETFE-foil is made out of a very light and highly transparent flour polymer. It allows 95 % of the sunlight and all over that the UV-radiation penetrating inside a structure.

In former years this foil has been used for greenhouses only, just clamping or clipping the material to a steel or aluminium frame. Since no weaving is inside, carrying loads, the size of the elements was and still is limited. Today using the ETFE-foil in air supported cushions with two, three or more layers exceptional structures are possible. Nevertheless in the past the size of those cushions was
limited to a size smaller than 50 to 60 sqm mainly. In principal it is not bad to start with smaller sizes while learning what the material can do.

But one must admit that this cushion sizes already allowed building “artificial glass structures” with less than 70 % of the weight of a primary structure necessary for normal glass roofs. The reason for that is on one hand the wider span and on the other hand the low weight of ETFE-foil cushions (approx. 1 kg/sqm for a triple layer cushion). At this point one should not forget that beside the outer loads like wind and snow due to the air pressure additional forces have to be calculated in order to dimension the necessary profiles. Today few of those companies, handling the ETFE-foil material, know by far more about the material.

Now it is possible to do the next dimension steps. This can be shown on the basis of the large ETFE-cushion-roof which was built by Ceno Tec GmbH recently for the project Tropical Islands near Berlin. 20.000 sqm of roof has been rebuilt by using 56 ETFE-foil cushions each measuring approx. 360 sqm ‘Figs 2 and 3’. The whole structure of each of the 4 fields is carried by a double layer rope net. That gave the possibility to reduce the overall weight of the secondary steel parts to a minimum of 4 kg/sqm.

Inside the Tropical Islands they have built a tropical rain forest and a large tropical sea. Not only for the plants, but also for all the guests who are willing to get there sunburns it was essential to have a material, which allows the UV-radiation to penetrate into the hall.

Figure 1. A large air supported cushion at the Expo Seville 1992; Size: 90 x 65 m. © Ceno Tec GmbH

Figure 2 and 3. The ETFE-foil-roof at Tropical Islands, outside and inside © Ceno Tec GmbH
Another Holiday Inn Barcelona?
A computational design method for enhanced conceptual design

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1 Introduction

The architectural domain is generally known for its connection between the world of art and the world of science. This results in a complex field of all kinds of soft and hard information. The architectural design process is therefore a complex process, which consists of many forms of information. Many, often vague and interrelated, design criteria shape the architect’s initial idea into the resulting form. The choice of these criteria and the guidance of this process is mainly done by the naturally limited short term memory of the architect. In this sense it might seem strange that the use of computers in this process is still limited, whereas the use of computers in for example the design processes in the aviation industry is standard. In this master thesis research has been conducted to the reason why the use of computers in the architectural design process is so limited. The conclusions of this research have been implemented in the computational process of designing a hotel in Barcelona.

2 Computational design

In most architectural offices the computer still plays the role of a digital drawing board or rendering machine. According to Watanabe (2002) we should seek ways for the computer and the brain to complement each other and collaborate in the architectural design process. We should use the computer as a tool for thinking. To accomplish such an integrated process, first of all the architectural design process itself should be described. As is mentioned above the architectural design process is a complex process which is according to Van Berkel and Bos (1999) dominated by a-posterior rationalisations. To be able to implement the computer in the design process, the organisation of the design process should be defined more elaborate.

According to Alexander (1966) every design problem begins with an effort to achieve fitness between two entities: the form and its context. The form is the solution to the problem, whereas the context defines it. But because of the impossibility to describe the context flawlessly, it is also impossible to describe the design criteria, which will achieve a fitting form. This is why architects construct thought models which try to answer the context as much as possible. The strength of a good thought model is its flexibility during the design process. The process consists of multiple design cycles in which during each cycle more information is generated. In this way the thought model is filled with increasingly more information. Computers on the other hand do not think, they follow rules. The
fundamental problem of computers is that ‘pure’ data itself (whether it is a row of numbers or a piece of marble) is not enough to generate a hypothesis or a form. An idea, a vision or maybe an accident remains needed to start a design process.

A computer model consists of fixed scripts, which need predefined and concrete information. This makes the computer model less flexible in accommodating new information. Designing is in computer terms a multi objective optimisation problem. Several objectives have to be met at the same time. This is a process in which the computer with its enormous computational power can become very helpful. It even becomes possible to search for optimal solutions for the given input by using Genetic Algorithms. In this way walking distances for personal in hospitals could be optimised. The difficulty of composing computer scripts is to decide which information will become important during the design process and how this information should be translated in computer scripts. To function realistically a computer model needs much information, information which is not always available or concrete (yet). Because of the complexity of both the context itself and the architectural design thought model it will be very difficult to program a computer model which will design an actual building.

3 The design criteria and the computer model

The design task of this master thesis is the design of a hotel in Barcelona, which consists besides hotel rooms also of public functions like a cinema, an exhibition area and a restaurant. By incorporating these functions not only tourists but also locals can use the building. The location is situated outside of the ancient city centre near the roundabout of Gloriés and the Torre Agbar of Jean Nouvel. The initial idea was to let these functions react on the urban context of Barcelona. Because it was impossible to translate all design criteria influencing the design of the hotel into computer scripts, a selection of criteria has been made. The selected design criteria are visibility, proximity and morphology of the site. The visibility concerns a number of (prominent) urban elements in Barcelona, which should be visible from certain functions, like the Sagrada Familia or Mount Tibidabo. Proximity concerns the distances based on considerations of functional relations among the hotel functions, which make proximity desirable. The morphology concerns the specific form of the location, which limits the area of possible positions of the functions.

In the computer program Virtools a model has been developed which generates a real-time and interactive 3D functional scheme by applying the design criteria mentioned above. Virtools is a computer program that is mainly used in the computer game development industry. It is possible to animate 3D elements in a 3D world by applying scripts to these elements, without using computer-scripting languages. The Virtools library consists of many predefined scripts, called Building Blocks, which the designer can use to build specific and complex scripts.

The computational method employed in this thesis is parallel local search, also known as Swarming Algorithms. Although this method is computationally effective and its implementation straightforward, it has significant drawbacks in finding the optimal solution. Due to the nature of Swarming Algorithms, where each parameter autonomously is improving its condition rather than being guided by a process that takes the total performance of the composition into account, this method tries to find optimal solutions, but it also finds less optimal solutions. These are called partial optima. It means that it is possible to find different solutions for the same input and that there is uncertainty about the degree of optimality. Genetic Algorithms are able to find the optimal solution, but the implementation of this method into this master thesis was beyond the scope of this project.
Figures 1 & 2. Swarming Algorithms do not necessarily find the absolute optimum. They also find partial optima. The model will remain stuck in alternative D because C and E are worse alternatives, it will not find the absolute optimum M.

4 The implementation

As mentioned above the hotel functions will react real-time and interactive to three predefined design criteria. Because the computer model is comparing information, this information should be quantified and qualified. How to define these criteria is also the task of the architect. Like in the normal design process, also in this process there should be a reason behind the choice of the information. To ensure a complex system of relations between the functions themselves and their view points and to avoid the clustering of functions at the same location, six different room types have been introduced. These room types are based on themes that can be connected to the lifestyle of Barcelona. These themes also provide reasons why one room type does have a more important relationship with a public function than another room type. For example, the relationship between a ‘sports’ room and the gym should be more important than the relationship between a ‘business’ room and the gym. Next to that a ‘beach’ room should always provide a view of the sea. The relationship between the hotel functions (defined in meters between the functions), the importance of this relationship (defined in a scale from 0.1 to 1.0) and the desired views from the hotel functions on urban elements in Barcelona, are placed in a matrix which forms the input of the computer scripts.

Figure 3. The relationship matrix which forms the input of the computer scripts. In the matrix the distance between the hotel functions, the importance of that relationship and the desired view is listed.
Composing and building the scripts of the computer model was mainly a process of trial and error. Because of the inability of computers to think for themselves all important but also seemingly insignificant aspects of this process have to be translated into scripts to accomplish a well performing model. To provide the desired view the hotel function should not only check if its position exceeds the height of the building between the hotel room and the desired view, but also if other hotel functions are not interfering the desired view. The hotel function should know the position of other, nearby, functions, the position of the desired viewpoint and the shape of surrounding buildings. This is why the city of Barcelona and the hotel functions themselves have been translated into a 3D world. Because Virtools rebuilds this 3D world every frame (per second on average 15 frames are displayed) and in every frame about 500 relations are computed, the program becomes quite slow. Another drawback is that the model does not come to a stop because of the many relationships between hotel functions. There is always a relationship that can be improved and because all hotel functions react on each other a dynamical balance instead of an optimum is found.

Figure 4. The Virtools interface. In this computer program the scripts (below) can be applied to elements (in this case the hotel functions) in the 3D world (above). The scripts will generate 3D functional schemes for the hotel in Barcelona.

4 Conclusions

The result of this process is a 3D functional scheme that is formed by three design criteria. Because other (for example spatial, constructive or economical) criteria have not been implemented in the model an untranslated representation of the result into an actual building is impossible. After generating a 3D functional scheme of the hotel by using Swarming Algorithms the actual design of the building is also partly developed by computer. In Virtools a mesh is generated around the 3D functional scheme which forms the skin of the building. Because the mesh consists of triangles the mesh can be used constructively. Inside the mesh a ‘route architectural’ connects all hotel functions. Because it was almost impossible to relocate the position of hotel functions (why otherwise build a computer model?) and for example accessibility was not a design criteria the design of the actual building was complicated. Both generated forms (the 3D functional scheme and the skin of the building) are the result of form-finding processes, in which the architect does not design the form itself but the process that generates the form. This form is the result of collaboration between designer and computer. Because the computer model needs specific and concrete information, the context has to be analysed more elaborate than in the normal design process, which generates much information.

Because of the vague and changeable nature of the architectural design process an ‘ideal’ computer model should be able to provide the designer a degree of freedom. It should be able to test the form at any given time and suggest improvements. These suggestions could surprise and inspire the designer. In the future the designer will certainly not disappear if the computer is able is to make design decisions. It generates more possibilities because the computer can offer certainty in design decisions.
5 References

Adaptable building comfort an integral approach;  
Follow the occupants and the sun

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ABSTRACT
The focus on the needs and drives for adaptation of the building automatically leads to changing needs and demands of the occupants of the building. Building should really take care of its occupants and show adaptable behaviour and reaction to the changing outdoor environment during the day. Design for adaptability should start with the occupants needs for comfort and indoor air quality. These are partly influences by the changing environmental forces as wind and sun. Weather predictions and the aggregated voting of users about their thermal comfort, should be the leading parameters to adaptable comfort and the adaptable building.

1 Introduction
Building design is a fascinating, it starts with a blank sheet and ends with a building with spaces and materials. Since the future is unknown, it is only possible to paint scenarios, possible futures, buildings have to meet. A building usually has to comply with more demands than mentioned in the list of specifications, for example because they were overlooked by the client, or necessary changes during the design process. In the continuous analysis, there are hard to quantify demands, such as comfort, beauty, social acceptance and safety. The designers has to pay due attention to all aspects, how trivial or unexpected they may seem.

Inappropriate formation of the design team may result in ineffective design process and solutions. Many problems emanate from a lack of integration between architectural design and design of indoor climate. After the industrial revolution, the natural relationship between design, construction and the built environment disappeared and has been replaced by a complex system of decision making, complex legislation, a subdivision of a whole integrated building into subsystems and disciplines in the construction process.

2 Levels & Hierarchy
The making of the built environment has become complex. In the conceptual design phase, in order to create conditions that assure a built environment that gets better, the ingenuity of the whole design
team existing of different disciplines should be used, not only architecture. The quality of the team should be combined with a well considered process of decision making. Techniques are selected and put together by a team in an integral design process. In addition to the application of proven construction methods, the integral approach demands an attitude of openness and appreciation of the other participating disciplines and their positions.

This approach makes it possible to combine and develop different kind of aspects in interaction to each other. During the design process participants and their decisions are structured at several levels of decision-making; the infill-level, the support-level and tissue-level. On each level there has to be made a balance between the performance of supply and demand for the building during the life-cycle. The basis of this ‘level-thinking’ is that of the Open Building [Habranek 1961].

Open building is primarily intended as an organised way of responding to the demands of diversity, adaptability and user involvement in the built environment. In open building the built environment is approached as a constantly changing product engendered by human action, with the central features of the environment resulting from decisions made at various levels.

A central idea in Open Building is to respond to the various needs of individual users through the phasing of the design and implementation process. In order to provide prospective occupants with the opportunity to influence their building, the elements decided by the occupants must be easy to change. Thus adaptability is not merely a means for modifying the dwelling during use; it is first and foremost a strategy for enabling the fulfilment of individual wishes without compromising. Thinking in levels is the basic Open Building principle.

Techniques are available to help further organize the complexities of environment as a subject into its component part and wholes. Dissecting a subject into its intrinsic parts and then shifting to how those parts are organized into a whole, allows access to content as well to the way parts connect and, therefore, to a full definition. To characterize connections a hierarchy is needed to outline sequence and progression and to illustrate part-whole relationships.

During design support, it is important to transfer the essentials of the proposed structures and mechanisms, without overloading other member of the design team with unwanted details. This information control can be achieved by use of abstraction. So far, many building teams have been sending their partners detailed drawings, thus relying on the addressees to make the necessary abstraction themselves. With the increasing use of product information models, it is now possible to incorporate multiple abstraction levels in the design representation. Abstraction is the mapping from one representation of a problem to another, which preserves certain desirable properties and reduces complicity [Giunchiglia et.al. 1997]. Abstraction is the selective examination of certain aspects of a problem. The goal of abstraction is to isolate those aspects that are important for a particular purpose and suppress those aspects that are unimportant [Rumbaugh et.al. 1991]. This enables representations to take an appropriate (abstract) form that matches the needs of the design specialist, thus saving much time and confusion.

Throughout the different levels of abstraction, the description of the building design gradually becomes more and more detailed. The various levels of abstraction should be considered as representations of a particular view on the total information available for a design.

This integrated design model must:
- be able to distinct related information,
- support distinctions related to the different levels of abstractions (views) by being structured into corresponding sub-models,
- ensure the satisfaction of consistency and completeness constraints linking different levels of abstraction in the design process.

Methodical Design [van den Kroonenberg 1979, de Boer 1989, Blessing 1994] can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution. The original methodical design process is extended from three to four main phases, in which
eight levels of functional hierarchical abstraction, stages can be distinguished. A feature of the extended model of Methodical design is the occurrence of a four-step pattern of activities in each stage.

Hierarchy can be used as a simplifying organizational tool to order and relate the parts of a subject in range-large to small most important to least, etc., used in a neutral sense where all parts are unique and important. Hierarchy theory in this way, frees minds from the analytical mode without requiring them to reject it and provides, as well, glimpses of a wider, more diverse world. Hierarchies suggest an interplay between parts and wholes and between the two basic modes of thinking:
- Analysis: separation of a whole into its component parts, the examination and study of each part;
- Synthesis: the composition or combination of parts or elements so as to form a whole.

This organizational structure provides a way to study and design complex issues. With regard to the built environment the parts human, built and natural environments can be analysed separately and then synthesizing the parts together to form a composite definition to obtain more meaning like a word integrated into a phrase and then into a sentence.

To work effectively with methodology, practitioners should learn to work with, and understand, the role of methodology in the building design process. Often means and goal are mixed up. More and more the insight is growing that it is not the building to be designed that should be central but the needs of the humans for which the building is intended.

3 Follow the occupants needs

For about 40 years there is an evolution of thinking and research in this way, strongly related to the integration of disciplines in proces and product. The most important new idea is taking man in his environment as the departure point, variable and criterion. The comfort of the occupants becomes leading.

The first guidelines for thermal comfort in the Netherlands were developed in the late seventies and eighties. They were based on the theory of Fanger and resulted in the PMV-PPD relationship, which predicts the percentages of dissatisfied occupants. Extensive field research however by de Dear showed that people have various adaptation mechanisms with most important people’s expectations of the building’s climat, based on the actual outdoor temperature. New thermal comfort models based on the human adaptability were developed over the past years. Applying adaptive thermal comfort, a distinction was made between different types of buildings, usage and climatic circumstances. An important feture to distinguish between the differences here is the possibility of individual control [van der Linden et.al. 2006].

The representation of situations with multi end-users, multi-individual control, was realized by developing an individual voting system. This voting system implied that every user in a thermal zone could enter his or her vote, warmer or colder, within a voting period, e.g. one hour, while seeing the aggregated voting of other users in his zone at the moment of voting.

The new user behaviour control strategy was implemented in a BMS(Building Management System). This BMS was extended with an external real-time information system to improve energy and comfort control.

To further enhance comfort and at the same time reduce energy consumption of buildings, new control technology is needed. Technology in which the end-user behaviour and preferences are integrated into a responsive ambient surrounding. Improvement of the energy consumption is made possible by agent-based systems for energy management in buildings, as well as new possibilities occur to enhance individual comfort of occupants.

On this philosophy, design teams can develop buildings with contrastful attributes for temperature, wind, humidity, daylight and smells. Buildings similarly gain a contrastful microclimate that changes in accordance with the time and the outdoor conditions, as well as a more pleasant interior, a space that will endure longer than we may imagine.
4 Integral approach

The search for a building that functions better within its surroundings forces architecture into every closer company with engineering. These buildings take advantage of the prevailing climatic conditions in combination with the familiar physical principals of natural draught, sunlight, wind, precipitation etc. The climatic conditions of the location are highly determinative for the form of the building, thus producing a climate-related and regionally distinctive architecture. Intensive collaboration with technical consultants takes place from the outset in these designs.

In 2000, the Royal Institute of Netherlands Architects, BNA, TVVL and the Delft University of Technology have participated in a research project called Integral Design. Observations in the construction industry show a fractionated process by different parties achieving their own aims, working on the same building. Different cultures and different traditions, many times conflict with the common aim of completing the building. The initiators of the Integral Design project had the vision that breaking the barriers of different trades may be the first step to a better built environment. It was named Integral Design and unfolded ways to implement, investigate, teach and learn the integral approach (2). The Integral Approach in relationship to Integral Design has to deal with different scale-levels and different ‘kind’ of aspects. To give the range of aspects which are related to the Integral Approach, not in the way to give a definition, in the way of describing, shows the interweaving mechanism between the several aspects and the area and approach which belongs to the word ‘Integral’[Zeiler, Quanjel 2001a]

The ‘umbrella-aspect’ is the flexiblity and bandwidth in process, designmethodology, constructionmethodology and facility-management. The integral approach will guide, interdependent to the value-frameworks, will control and correct and will leave room to the specific method or solution for the several participants during the total process.

The Integral Approach is conceptual and therefore inhabits the several ‘specific methods’ such as for instance Strategic Design, Sustainable Design and LCA-Design. The Integral Approach is related to the longer term for different (time, site, process and program) settings; a sustainable approach [Zeiler 2001][Zeiler, Quanjel 2001b], [Brand et.al 2001].

The integrated building design process is one which considers all aspects of a building, its environment and life cycle, and is undertaken by a team which includes all relevant professionals and stakeholders working together throughout the process rather than sequentially and independently.

5 Internal adaptability

Internally, structures satisfy and symbolize human spatial needs, wants and values; externally they provide and symbolize a protective envelope, an interrelationship with the outside environment. The external enclosure can be considered the “third skin” of the human body and its comfort (light, fresh air, optimum temperatures, etc.) is based upon human senses and either provided for by natural means (windows for light, solar energy for heat, shade for cooling, etc.) or by artificial means (electric lights, heating, air conditioning, etc.). The project ‘rotor haus’of Colani shows how internal adaptability of use of specific functional rooms is possible. Nevertheless because of the major influences of the sun, outside adaptability is more important in relation to energy and esthetics.
The external character of a building form is shaped not only by internal requirements, but also by fitting a building to its elusive environmental context. Designing with local climates and sun orientation, with similar construction methods and materials, can increase human comfort and reduce energy consumption. Building, indeed, must consider and respond to its built environmental context but also to its natural environment. Technologies should resolve conflicts between what the natural environment provides and human needs, sustenance and comfort.

To let the building react on the thermal comfort demands, it is effective to let the building react to the path of the sun. By letting rotate the building, its sun protection or both, with the turn of the sun the heat of the sun can be left outside the building or when needed let into the building. Different solutions were already realised in built projects. But there are more solutions to make buildings adaptive to the sun and the comfort needs of the occupants. Some of the realized projects show completely different ways of solution.
If a building is a working whole, a system, we can distinguish subsystems: the load bearing construction, the envelope, inner partitions, HVAC and MEP installations and many more. A building that can anticipate on an unknown future consists of building parts with different cycles of change, co-ordinated, yet uncoupled, designed by different disciplines, collaborating in a team, serving the client as well as the end user.

6 Conclusion

For the focus on the needs and drives for adaptability building comfort a process approach is needed in which the thinking of the architect designer is linked in the design-process itself with the engineer. Support both parties with information on the tasks and decisions of the other party and at the same time supplying an explanation of this information will greatly enhance understanding performance of combined efforts. The structuring of the communication of the process between architecture and consultants is based on abstraction, for instance the exchange of abstract descriptions of a design. Through the different levels of abstraction, the building model is gradually described in an increasingly more detailed manner. Thus decomposing complex design-tasks into manageable size problems.

The integrally working design team not only designs the building, it designs the design process as well. Continuous adaptation of the design and final decision making need to be balanced. Thus the design process is cyclical, spiralling up towards the final plan. The plan with its focus on internal and outside adaptability also determines the possibilities and impossibilities of construction, maintenance and management. It is therefore important to inform and hear the construction partners and the parties responsible for running the building. It is quite likely that a certain team will never operate again in the same configuration. It is therefore advisable to report on and evaluate the process in order to gain from the accumulated experience and techniques applied.

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