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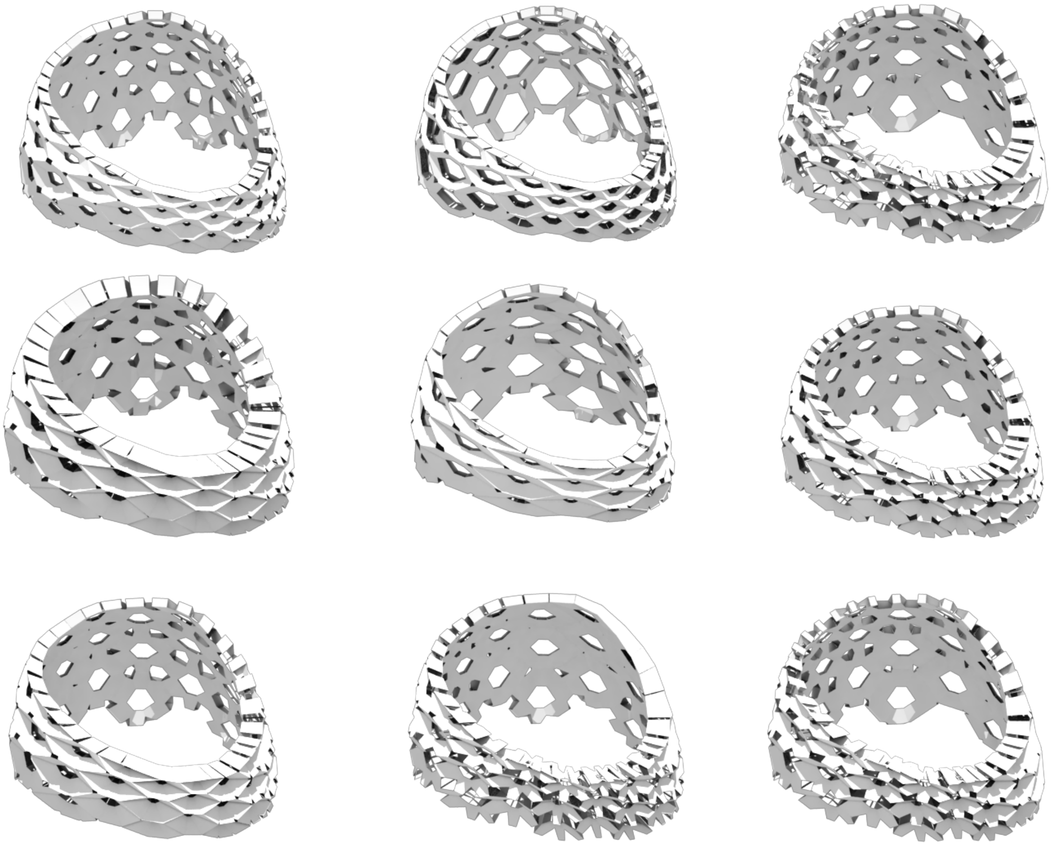

Design of Timber Structures in a Parametric Environment

Exploration of an alternative design process

Master of Science Thesis in the Master's Programme

Architecture and Engineering

LUKAS NORDSTRÖM
AGNES ORSTADIUS

Department of Civil and Environmental Engineering
Division of Steel and Timber Structures
Chalmers University of Technology
Gothenburg, Sweden, 2014
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Samples of design alternatives generated from a parametric model

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ABSTRACT

As awareness of the environmental and architectural benefits of building with timber increases, it becomes desirable for use in more complex projects, where demands on high performance require greater design adaptability, especially in early stages. This can be met by more closely integrating architectural, engineering and production requirements in new work flows from the concept stage of projects. The shift from mass production to mass customization, from design of individual structures to the design of structural systems, is made possible by a parametric method where the design model is constantly evaluated according to several design criteria. The starting point of this Master's thesis is the linear design process of timber production company Martinsons. The aim is to propose a new work flow and to investigate how the use of a parametric design platform in early stage design can change and improve the overall design process. The vision is a concept design platform which can handle complex geometry and lets the model be informed by live updated structural analysis, material properties and production limitations. Together with a general knowledge of stuctural systems and familiarity with production conditions this tool will allow a much greater adaptability early in the design process, helping to avoid costly late phase changes.

In this thesis 3D-modelling software Rhinoceros and its parametric plugin Grasshopper are used, linked to the FE-analysis program Oasys GSA to exemplify a parametric work flow. A new design process in a parametric environment is explored through a series of tests, including complex geometrical modeling, global structural analysis using bar and beam elements, detailed mesh analysis, combining local and global analysis and geometrical modelling with implementation of physical material testing and production limitations. It is found that although the tools used are fairly new and untested, they are already a powerful alternative to existing processes in the concept stage of design. A parametric design platform does not autogenerate design solutions and should not be seen as a replacement for design competence. Rather, it is a tool to help designers extract the potential of computer capacity, in processor-heavy tasks such as defining and generating complex geometry or analysing multiple structural solutions. With this expanded capacity of the parametrical environment in terms of both design and production, the imagination and skill of the designer become the only limitations.

Keywords: parametric design, digital production, concept design, timber engineering

Design trästrukturer i en parametrisk miljö
Undersökning av en alternativ designprocess

Examensarbete inom Masterprogrammet Architecture and Engineering
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Institutionen för bygg- och miljöteknik
Avdelningen för trä- och stålbyggnad
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SAMMANFATTNING

I takt med att träbyggandets fördelar för miljö och arkitektur blir mer kända ökar användandet av det i mer komplexa projekt, där höga prestandakrav kräver större flexibilitet för designen. Detta krav kan mötas av att närmare integrera design och produktion i nya arbetsflöden, som möjliggörs av utvecklingen av digitala produktionsverktyg. Vi ser ett skifte från masstillverkning till "mass customization", där digital information låter maskiner skräddarsy varje byggnadsdel utan att effektiviteten minskar.

Syftet med detta projekt är att utforska hur ett nytt parametriskt arbetssätt skulle kunna påverka designprocessen av träkopplingar. Genom att jämföra med dagens metod, som består av separata faser och krävande mellansteg, vill vi undersöka möjligheterna som skapas av att arbeta i en enda digital miljö för design, analys och produktion. Vårt mål är sedan att koppla in denna parametriska plattform i den existerande produktionskedjan.

Nyckeln till en parametrisk designmetod ligger i en multifunktionell plattform som kan länka ihop flera delar av designprocessen i en enda modell. I denna modell skapar matematiska samband och regler en geometrisk representation som kan modifieras enligt olika mål. När man kopplar detta till analysverktyg så kan resultaten direkt påverka geometrin.

Vårt mål är att skapa en snabbare och mer flexibel process där det är möjligt att skapa och utvärdera många olika varianter av en design beroende på vilka analysresultat man får och eftersträvar. Resultatet av projektet är ett byggt exempel för att demonstrera detta, och därigenom visa på möjligheterna som skapas av en närmare koppling mellan arkitektur och konstruktion.

Nyckelord: Parametrisk design, digital produktion, konceptuell design, träteknik

TABLE OF CONTENTS

PREFACE

This thesis comprises 30 ECTS and has been carried out during 2013 at Chalmers University of Technology (CTH) in Gothenburg, Sweden. The project has been carried out under supervision of Karl-Gunnar Olsson, professor of Architecture and Engineering at CTH. Robert Kliger, professor at CTH, has acted as the examiner of the thesis.

This project is partly integrated with a parallel Master's thesis in Architecture and has been developed with that in mind. An original aim of the thesis work was to produce a small pavilion to be exhibited at Virserums Trädagar 2013 and at Trä & Teknik-mässan in Gothenburg in 2014. The conclusions of the thesis were presented at the Wood Summit Conference in Skellefteå, Sweden in November 2013.

ACKNOWLEDGMENTS

First of all, our supervisor **KG OLSSON** has, as the founder of our candidate program Architecture & Engineering, been an unceasing inspiration for the past six years and a steady guiding light through the work with the thesis.

Martinsons' **GREGER LINDGREN** has generously donated his time to answering our many questions and welcoming us to their facilities. **MARCUS ABRAHAMSSON** has been an invaluable collaborator throughout the project, on the trips to Switzerland and Skellefteå and during the concluding work on the report. GSA Grasshopper plugin developer **JON MIRTSCHIN** has been amazingly helpful, not only making this work possible at all but also answering our questions.

We would also like to thank our examiner **ROBERT KLIGER**, **MARKUS HUDERT** at EPFL, **ZEENA FAROOK** at ARUP for the GSA license, **MORTEN LUND**, architecture professor at Chalmers for inspiration, **THE MATTER SPACE STRUCTURE STUDIO** for good company and a great working environment and our eminent opponent **ALEXANDER SEHLSTRÖM** for many interesting discussions during the course of the thesis work.

Finally we would like to thank **OUR FAMILIES** and **LOVED ONES** for all their support.

Gothenburg, Sweden
2014-04-07
Lukas Nordström
Agnes Orstadius

1. INTRODUCTION

In this chapter the context, purpose and limitations of the project will be introduced and an outline of the thesis presented.

1.1 CONTEXT

Despite Sweden's vast natural resources of forest and large timber export industry, the technical innovation in the field of fabrication is lagging and the percentage of use in construction remains low. In 2012 only 10.1% of large residential buildings were constructed with a timber structural system. [Byggindustrin, 2013]

Internationally, timber is making a comeback as a high-tech building material. Sustainability advantages play a large part in this renaissance. The comparatively low ecological footprint and numerous beneficial environmental effects of timber construction (compared to steel and, especially, concrete) has increased demands for its use in more projects [SP, 2013]. At the same time, the progress of digital fabrication, where tools can be programmed to produce detailed and non-repeated geometries without loss in efficiency, make possible the production of components featuring previously unseen complexity [Neumann and Schmidt, 2007]. These parallel phenomena - increased interest in new ways of using the material, as well as new fabrication methods - create opportunities for developing new ways of working industrially with wood in order to realise geometrically and structurally complex structures.

Today, architects and engineers involved in complex projects often work in different phases and with a separate set of tools. The delays currently caused by software conversions between independent models, as well as by lagging information exchange make projects inflexible and vulnerable to changes and misinformation [Mirtschin, 2011]. In order to reach the full potential of complex projects, the architects and engineers involved must work closely together [Shen *et al*, 2010].

A parametric model, also known as a *definition,* is a method of digitally modeling geometry which combines input information in a series of commands, describing mathematical operations and from this generates output in the form of a 3D model. When the inputs change, the operations are performed again, creating a different output. In the parametric environment, "the form per se is no longer drawn, but rather a process is defined that generates the form". [Buri and Weinand, 2011]. Since the inputs can be changed infinitely and rapidly, generating different results each time, many different iterations can be evaluated in a short time. By incorporating analysis results directly into this parametrical environment, the model designed can be immediately informed and improved by the analysis result. Optimization motors can be also be incorporated to find an iteration defined as optimal from a set of expressed criteria [Sehlström, 2013].

The inputs of the definition can include information such as maximum measurements, required span length or any information that is quantifiable. Connecting the different phases of design and production in a model that is based on the initial requirements which are set for the project and which can be modified when new information is received, could greatly decrease design efforts previously wasted because of lack of information [Mirtschin, 2011]. This better connected process could not only decrease project time and cost, but may also increase the potential for performance-driven architecture and lead to more sustainable structures.

1.2 AIM

The aim of this thesis is to explore a parametric work flow for design of timber structures in the concept design phase, with focus on structural optimization. This specifically includes exploring the integration of FE-analysis of a structural system into the generative platform Grasshopper. The proposed work flow will be compared with the existing design process of the timber producer Martinsons and the potential of the parametric work flow will be evaluated in different case studies.

1.3 LIMITATIONS

Though many parameters can be incorporated in a parametric design process - energy use and light intake are already common areas of application - only structural efficiency will be treated in this thesis.

The explored work flow is contrasted with Martinsons design process, but will not be fully implemented.

The parametrical environment used is Grasshopper, which is a generative plugin to the 3D-modelling program Rhinoceros. This was chosen due to its popularity and amount of connected applications available and because of previous use and proficiency. The structural design plugin GSA was chosen because of its advanced capacities and since it is one of few compatible programs that currently support material orthotropy.

1.4 THESIS OUTLINE

This master´s thesis consists of a theoretical and an experimental part. The theory provides the framework and context for the proposed work flow, whereas the experimental part uses that knowledge for recreating different parts of a design process.

Background
In order to understand the challenges of creating complex wood structures, extensive background information is provided. Study trips, conferences and collaboration with Martinson are discussed.

Theory & Method
The proposed parametric work flow is presented and discussed, investigation of the required software is made and to test the feasability of the work flow, sub process tests are chosen.

Sub Process Testing
Different parts, with increasing complexity, of the proposed work flow are tested and discussed.

Discussion & Future Work
The results are discussed in relation to the aim and potential developments of them are proposed.

1.5 THESIS PROCESS

Understanding how parametric design could enhance existing concept design processes required research on several topics. An orientation of parametric design was gained via articles and literature, mostly published fairly recently due to the emerging nature of the topic. A systemization of different existing timber structures was studied to understand important factors in the design of complex structures. Three study trips were conducted: the first trip was to Switzerland (Fig. 1.1) with surroundings, to visit structures and learn more about recent development in timber and digital production, the second was to the production facilities of Martinsons in Bygdsiljum and the third went to a conference in Graz, Austria to learn more about current production of Cross-Laminated-Timber (CLT). Parallel to these trips, interviews were conducted with Martinsons. Finally, a small pavilion was designed in May 2013 using the proposed work flow.

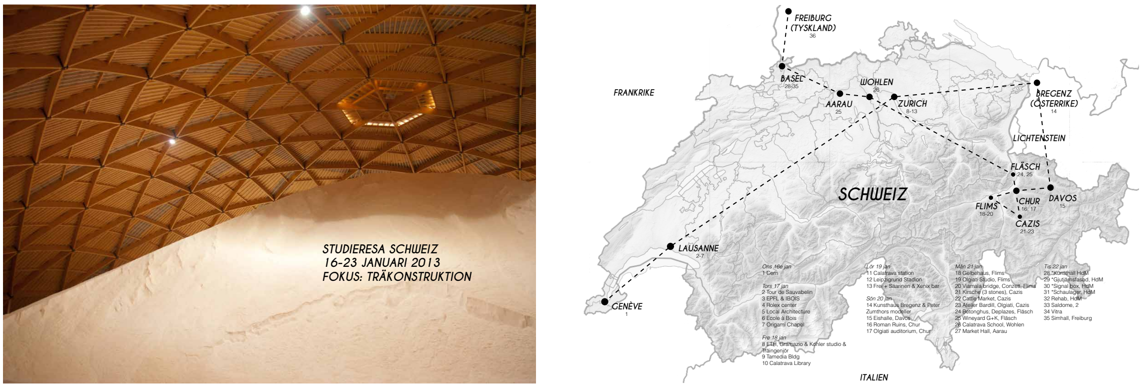


Fig 1.1 - *Pages from a booklet produced about the study trip to Switzerland and beyond (Orstadius and Nordström, 2013).*

2. BACKGROUND

In order to understand the structural design process of timber structures, as well as how a parametric work flow could be beneficial, a thorough background study has been conducted. The recent digital developments in timber production are placed in a historic context and an effort to understand the shift from designing structures to structural systems is made. The classification of structural systems as explored by Heino Engel is studietd. A typical design process is examplified by that of the timber producer Martinsons and recent production developments are outlined.

2.1 ERAS OF TECHNOLOGY IN THE HISTORY OF TIMBER PRODUCTION

The tools and information available to producers have always determined how timber has been used in construction. With the introduction of digital tools in both design and production environments, a change can be expected in the way wood is perceived as a material. Using modern processing (saw milling) and laser technologies, wood is relatively easy to work with in both a larger and smaller scale, making it an ideal material for a digital process. From being perceived as a old fashioned material during the modernist period, with its emphasis on the orthogonal concrete block, wood is now returning as a "high tech material" [Buri and Weinand, 2011].

In order to explain how the design and production of timber is changing, the architect Christoph Schindler (2005) has defined three major eras, or *waves*, see Fig. 2.1, through the history of wooden construction: *hand tool technology, machine tool technology* and *information tool technology.* According to Schindler, the information tool era is distinguished by parametric design and system thinking.

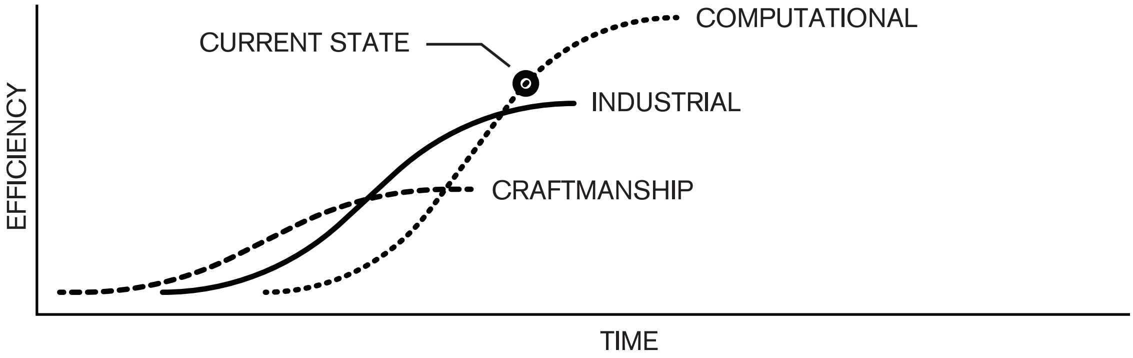


Fig 2.1 *After Schindler's model: the three waves of production technology. [Schindler, 2005]*

2.1.1 HAND TOOL TECHNOLOGY

Using hand tools when working with timber meant that logs were chosen, cut and sawn for a specific purpose. Since everything was made by hand it did not matter if the carpenter made ten unique or ten identical building pieces. A systematic numbering system where used to keep track of the individual parts for assembly [Gerner, 1994]. Typically, one carpenter was in charge of both planning and erecting the building, which led to a variation of architecture where buildings were based on local building traditions, materials and knowledge.

2.1.2 MACHINE TOOL TECHNOLOGY

The introduction of mechanical machines in wood production led to much higher production capacity through standardization of the pieces produced. A machine is “built for a specific repetitive action and cannot respond to information” [Schindler, 2005] - it was made efficient by continuously repeating the same action.

The production time of building components decreased and the concept of mass production was introduced. The machines limited the geometrical complexity of the building parts. The timber architecture during this era can be symbolized by the prefabricated house [Schindler, 2005], where interlocking wooden joints were replaced by steel connectors. The specialization and larger production capacity resulted in more people involved in the building process; the person cutting the logs was no longer also in charge of the construction site. This created a need to communicate and thereby led to the introduction of measurements and standardized profiles. Plywood and other timber engineered products entered the market and further tranformed the architecture from uniquely made to mass produced.

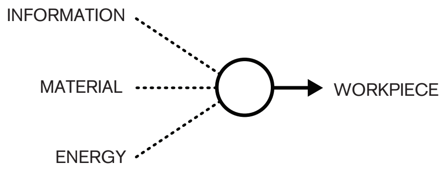


Fig 2.2 *The generalised production process. [Schindler, 2005]*

2.1.3 INFORMATION TOOL TECHNOLOGY

The introduction of information tools was made with Joseph Marie Jacquard’s weaving machine in 1801. This machine could process both material (wool), energy (steam or electricity) and information, in the form of punched hole cards. The same weaving-machine could now from different cards produce different patterns. For the first time in history, “man was the creator of the process and the machine the creator of the product”, see Fig. 2.2, Fig. 2.3), (Schindler, 2005).

The CNC (computer numerical controlled) machine was introduced in the 1970s and the first digitally controlled timber joinery machines debuted in the 1980’s. These machines introduced operations such as freely cutting, sawing, milling and assembling. This flexibility made possible a “one-of-a-kind-production” instead of the mass fabrication typical of the machine tool era. Now ten unique pieces, individually labeled and assembled, could be produced in the same time as ten geometrically identical ones. This approach of custom-making structural timber units is similar to that of the hand tool era. Choosing and shaping the piece of wood most suited for a certain structural task can be likened to custom-engineering timber materials and generating individual drawings to be produced by a CNC machine.

New mathematical representation of shapes also started entering the market with the introduction of the NURBS curve (non uniform rational B-spline). Now architects and engineers were no longer bound to straight lines; more complex forms could be achieved both in the computer and at the production table.

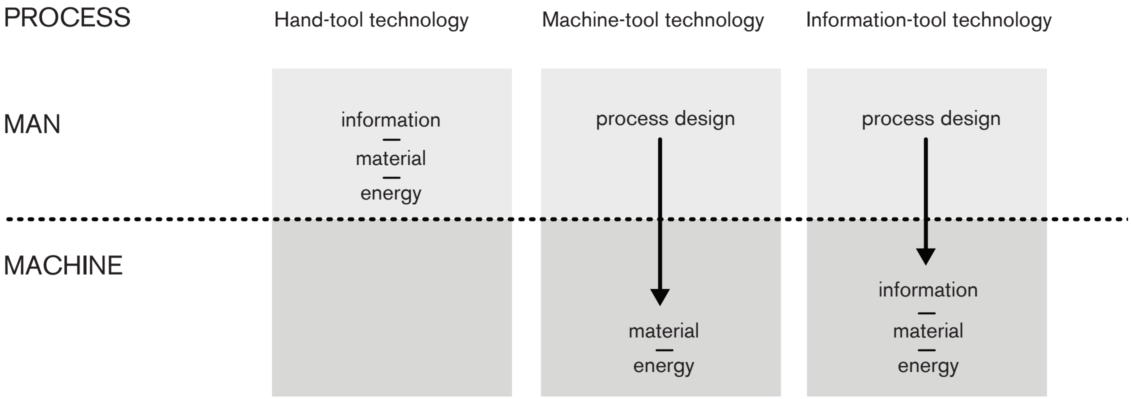


Fig 2.3 *After Schindler: the respective labour division of man and machine in the various eras. [Schindler, 2005]*

With these new opportunities in designing and producing timber structures, design expressions and engineering solutions are changing. Several exciting developments can already be seen: the use of the grid system for wood production is losing its relevance and the wooden panel is now replacing the bar as most versatile construction element [Deplazes, 2005]. The information tool technology has also reintroduced the wooden joint, since geometrical complexity does not necessarily pose an obstacle [Neumann and Schmidt, 2007]. When a unique wooden joint is used, “no further marking for defining the position is needed; two production steps has become one” [Schindler, 2005].

2.1.4 SYSTEM DESIGN - PARAMETRIC MODELING

With the introduction of information tool technology, the role of the producer is shifting from processor to process designer. In a parametric environment, the definition created by combining inputs is really a systemization of information, since the inputs can be changed and thus lead to different results. “What is decisive here is not the chosen form, but how the process for form generation has been set up and what parameters control the process. Such a design process provides an opportunity to incorporate the properties of the material and the support structure, as well as construction and fabrication techniques, as parameters into the process." [Buri and Weinand, 2011]

2.1.5 CONTEMPORARY EXAMPLES

Some built examples exist that show how a parametric platform can be used to optimise performance of a structure.

Camera Obscura, Trondheim

In 2006, architects from the University of Trondheim realized a project with focus on 1:1 file-to-factory wood production (Fig. 2.4). The project's objective was to see how a standard CNC production machine could produce geometrically complicated shapes. The project used Rhinoceros for 3D modelling software and production machines HundeggerSpeedcut SC1 and K2. One conclusion was how important it is to vary the scale of both digital and physical models in the design process. Another conclusion was also that this standardized CNC machines could be used in a more efficient way than they are today. [Larsen *et al*, 2007]

ICD/ITKE Research Pavilion, Stuttgart

This project (see Fig. 2.5) was about how "material has the ability to compute."According to the research group, "a material construct can be considered as the equilibrium state of an intricate network of internal and external forces and constraints." [Fleischmann and Menges, 2012]. A torus-like pavilion was built where the deformation measurements were fed back into the parametric model, creating a responsive and accurate digital representation.

London Velodrome, Hopkins Architects and Expedition Engineering

In the work with the London velodrome (Fig. 2.6), parametric models treating cost, weight and structural utilisation among other parameters were crucial to the design process. Several iterations of the structure were evaluated for performance.

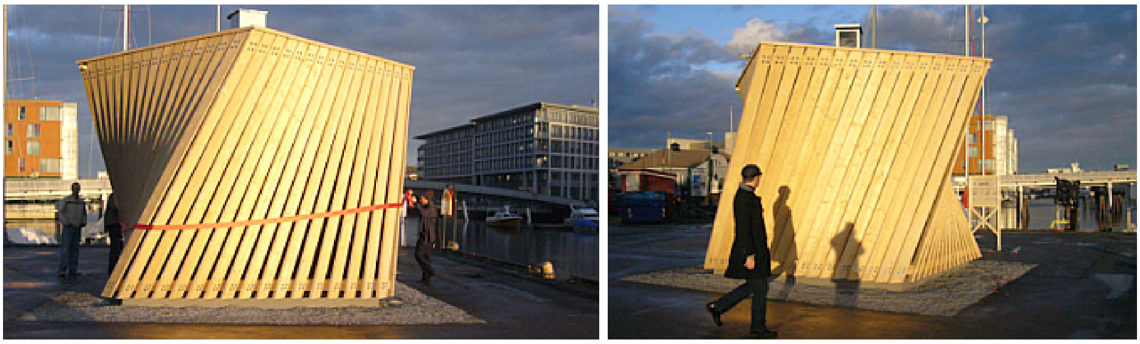


Fig 2.4 *Camera obscura pavilion by University of Trondheim. [Larsen, Knut Einar et al,2007]*

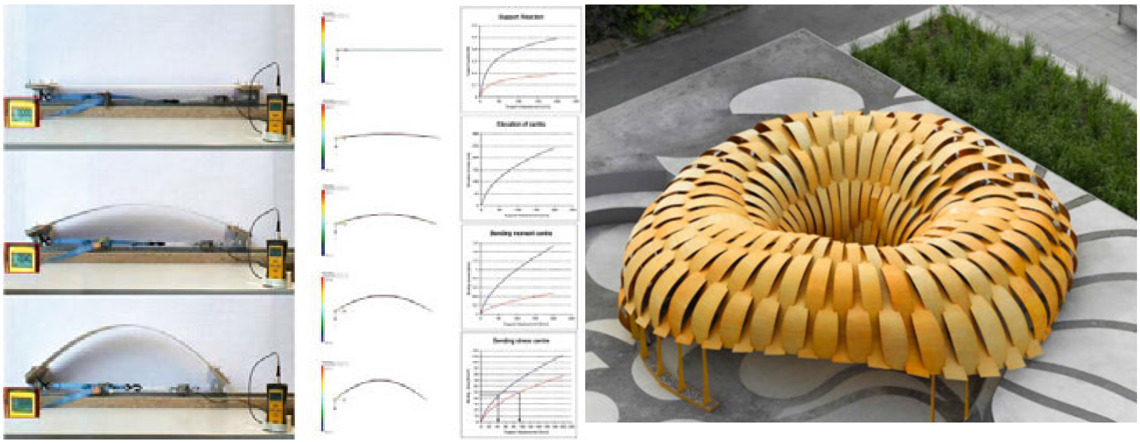


Fig 2.5 *ICD/ITKE Research Pavilion by University of Stuttgart, with bending tests. [Fleischmann and Menges, 2012]*

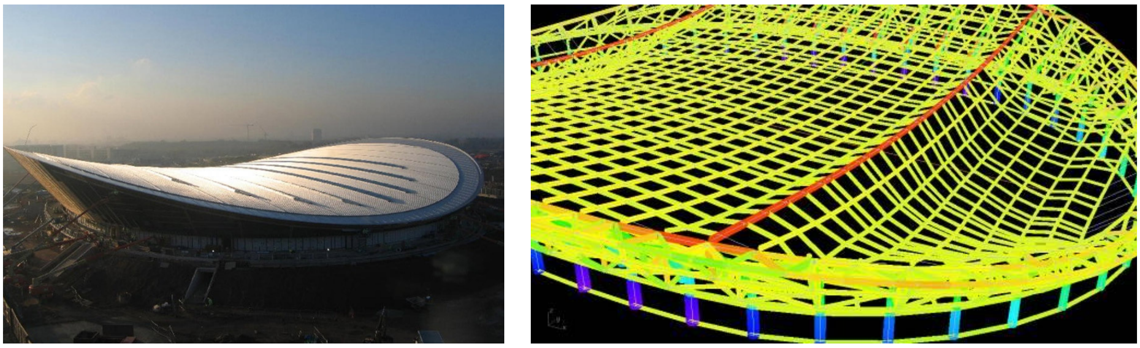


Fig 2.6 *The London velodrome, with a structural model during erection. [Designboom.com, 2012; Mirtschin, 2011]*

2.2 AN ORGANISATION OF STRUCTURAL SYSTEMS

2.2.1 SYSTEMIZATION OF GLOBAL LOAD STRATEGIES

In order to be able to design and model structures parametrically, tthe governing rules must be defined. These rules are geometrical and structural: all structures carry loads in some assumed way. By categorizing these different ways, a theoretical framework of structural systems is created, which can then be used in order to create a functioning system from different components such as beams, bars are wires. That is, not only to understand a global form, but also how it is built up, how it works structurally and what criteria have to be filled for it to function. These rules are of great importance in order to set up a structural parametric model.

Obviously, understanding the general behavior and the properties of the different structural systems facilitates early stage design choices (Fig. 2.7). One example is the span lengths of truss structures. By knowing the limitations of the different subcategories of trusses, a wise initial choice can be made. Once the type is chosen, a parametric model can be made for further and more detailed comparison between iterations of this type. This parametric model can be designed to include other information, such as production methods, material properties and utilisation of the structrure.

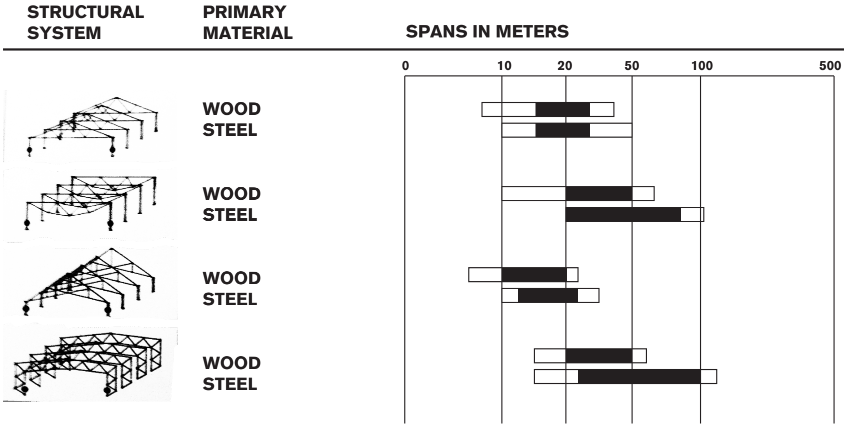


Fig 2.7 *Comparing the capacity of each structural system helps finding the most suitable for a specific project. [Diagram after Engel, 1997]*

2.2.2 ENGEL'S CLASSIFICATION: STRUCTURE SYSTEMS

Heino Engel [1997] has made a classification of structural types according to the way they handle loads; folded plates work in shear, space frame in axial forces and so on. In Engel's systemization all structures can be divided into *form active, vector active, section active* and *surface active*, describing how the loads are being arranged in the structure (see Fig. 2.8). This systemization will be used here to illustrate the extent of a parametric model of a structure.

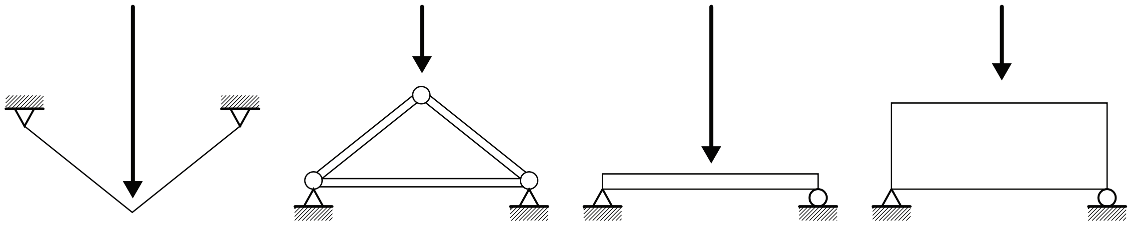


Fig 2.8 *Engels classification of the redirection of forces in structures; form active, vector active, section active and surface active. [Diagram after Engel, 1997]*

One important aspect of this systemization is the differentiation Engel makes between "structural systems"and "structures". In his view, a structure is a built example of a structural system: the latter is independent of scale, material, connection type, etc: a clear and clean representation of the primary loads it organises. This ties in neatly with the idea of parametric design, where what one really designs is a system (for example a structural system) with many possible variations, rather than one static form.

The systemization is presented in a diagram with subsections (see Fig 2.9) where the branches illustrate more and more specific structural types. When developing a structural system, one normally has to pick one specific shape to test (one branch from the far right), develop and evaluate. Depending on how general the code is written, in a parametric model, several branches can be evaluated at once.

2.2.3 REFERENCE OBJECTS

Several built timber structures has been studied according to various relevant parameters. This was done to attempt a similar organisation as Engel's and also to just become more acquainted with different existing structural systems. Some of the structures have been studied in detail and are presented in Appendix A. These structures are representatives of different types of load bearing systems: vector active, section active and form active.

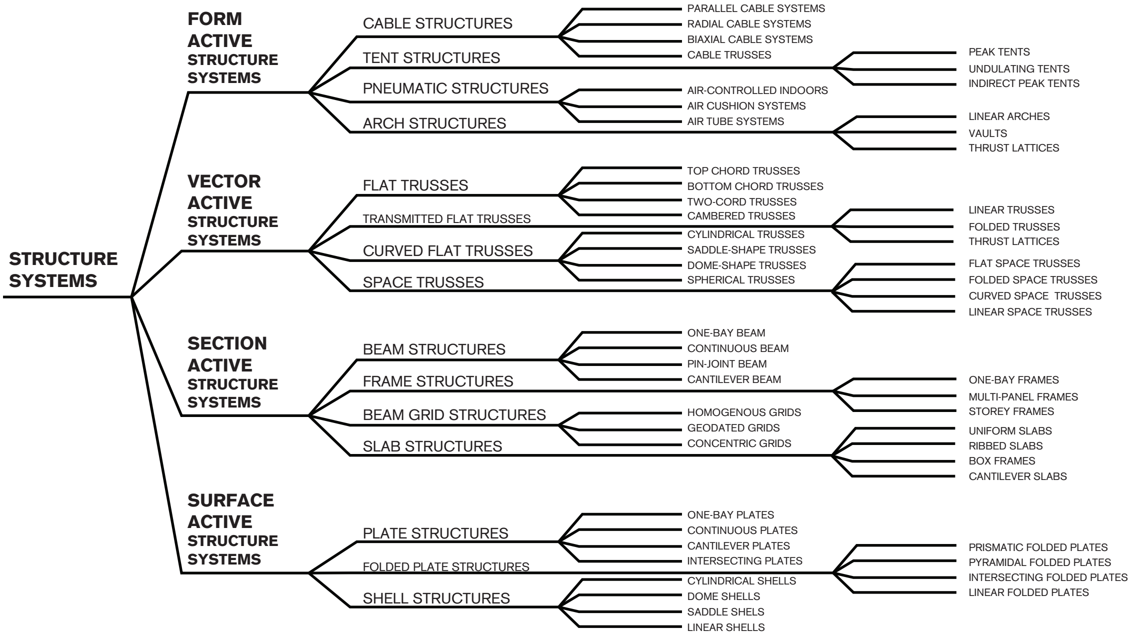


Fig 2.9 *When developing a structural system, one normally has to pick one specific shape to test (i.e. one branch from the far right), develop and evaluate. Depending on how general the code is written in a parametric model, several branches could be evaluated at once. [Diagram after Engel, 1997]*

Design process logic of bottom up

The process of finding the initial global form of a building is often characterised by a *top-down approach*. A form is chosen for non-structural reasons, for example an architectural vision for a specific shape. Later in the design process the structure is solved within boundaries of the architectural concept. This can lead to inefficient structures as the possibilities to optimise the structure are limited.

A bottom-up approach would instead refer to a design approach where the outcome is constrained from the beginning by the limitations of the materials, production methods and structural system defined as rules in the parametrical model. Structurally it means taking advantage of the conditions that different components create, by utilizing the global forms they provide prerequisites for.This is a suggested use for Engel’s systemization: the performance (such as span length, relative weight etc) of different systems can be compared, (see Fig 2.9) and ranked to find the most suitable.

One interesting question inspired by the reference objects [Appendix A] is the differentiation between sophistication of the detail or variation of the element (Fig 2.10). In mass production, the elements are often simple and the connections handle the variation in force. An advantage of digital production is the possibility of a flexible element consisting of variations on one systematized principle, endlessly changed to transfer different sizes of forces. This could mean a shift in geometrical and structural complexity from the connection to the element, or a blurred line between the two.

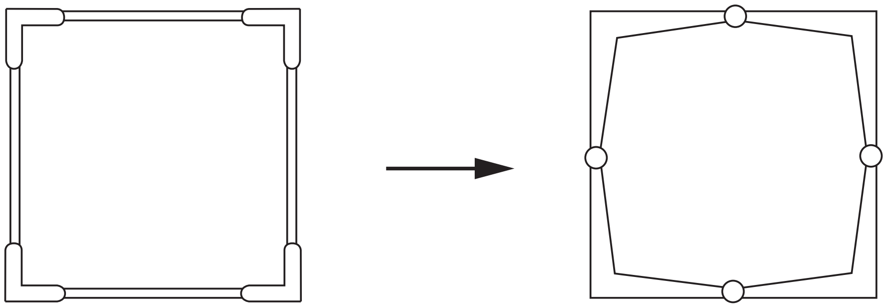


Fig 2.10 *The same effect can be achieved either by a connection that transfers the change in load, or an element that does. The latter can enable simpler connections and has become more relevant with digital fabrication. [Diagram after Engel, 1997]*

2.4 A GENERAL OUTLINE OF THE DESIGN PROCESS OF A STRUCTURAL SYSTEM

2.4.1 ENGEL'S DESCRIPTION OF THE GENERAL DESIGN PROCESS

In a typical process in the design phase, the project moves through steps that involve different professions. One attempt to describe the design process is made by Heino Engel [1997]. First, the different phases in the project at large are outlined (Fig. 2.11).

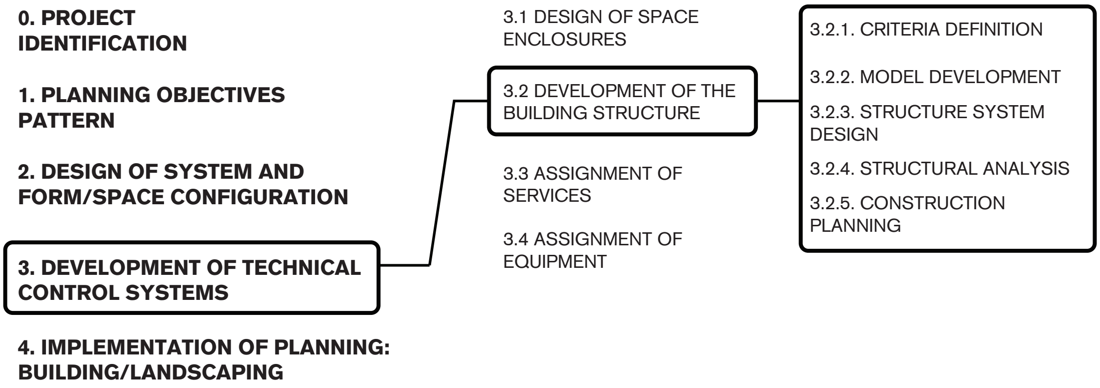


Fig 2.11 *Engels account of a project process. [1997]*

In this description, phase 2, where the form is considered and phase 3, where the structure system design can be found, are separated. This can be discussed; one could argue that the two are too inextricably linked to happen in sequence and rather need to be shaped simultaneously in order to create a truly efficient structure. Engel does emphasize the need for feedback loops; this guarantess "that the form impulses of structural design will become fully effective in the phase of form/space design" [Engel 1997].

This thesis is focused on the design process of the structural system, found in Engel's description as shown in Section 3.2. The theoretical description shows a linear design process, also with feedback loops, as described in Fig. 2.12. As the design progresses, evaluation of each proposal informs the next one. This evaluation is based on specified criteria. Revisions brings the process back to earlier stages, which is, of course, not favorable for the time or cost of the design process. In order to minimize the backward loops a well evaluated design at an early stage is necessary.

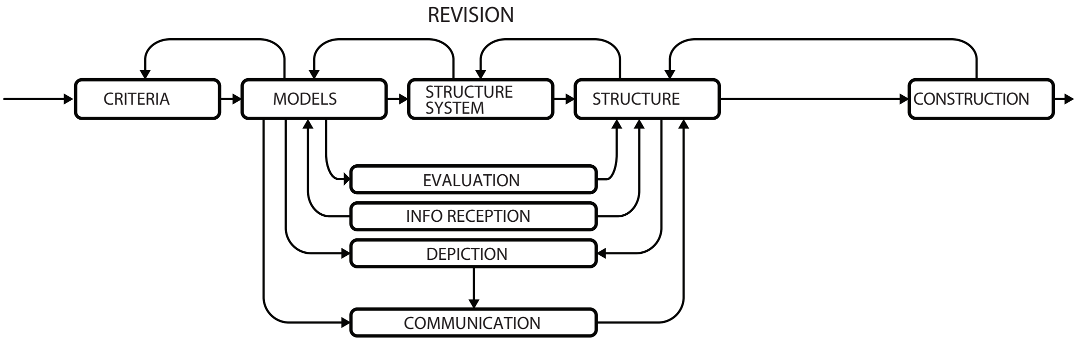


Fig 2.12 *Heino Engel's description of a typical design process.[Engel 1997]*

The criteria used for evaluating each proposal can be divided into categories, where some can be measured with simulation programs and given a number, while other criteria are more subjective. These are called *soft* and *hard* evaluation parameters, where wind, light conditions, stresses, weight and costs are examples of hard parameters, whereas beauty and spatiality are examples of soft parameters. The weighting and quantifying of these parameters create a framework for comparing and evaluating different designs.

2.4.2 COMPONENTS OF CREATING AN EFFICIENT DESIGN PROCESS

From this description, some guidelines can be imagined in order to minimize the risk for revisions and arriving at a suitable structure:

Evaluating early - while projects are getting more and more complex, the number of parameters in the design are growing. Therefore an early evaluation process is crucial, to know that the direction of the chosen process is right.

Evaluating many **-** many different systems could often fit the criteria for design but the time for evaluation is limited. The possibility to evaluate a large number of options simultaneously in a short time would therefore be important.

Evaluate precisely - the possibility to evaluate the results of many permutations in a short time is beneficial in the design process in order to save time.

2.5 MARTINSONS' DESIGN PROCESS

In order to fully understand an existing design-to-production process, a collaboration started with the timber producer Martinsons AB. Martinsons AB is Sweden's largest timber producers for glulam beams and wood building systems and currently Sweden's only producer of cross laminated timber. They were chosen as collaborators for this thesis because of their focus on innovation in the field of wood products, evident in their projects with CLT wood. Since they are one of the largest producers, their productions methods and priorities can be seen as representative for the current national situation.

Study visits to their factories were made on two occasions. Interviews with Greger Lindgren (development manager), over phone, email and in person, helped create an orientation of how their design and production process is structured. They are often responsible for the whole chain from manufacturing to production. The development has largely been focused on strong standardisation to reduce costs.

2.5.1 TYPICAL CASE

A rough outline of a typical design process is as follows:

- Preliminary drawings of the structure are received from an architect, or if it is a more standardized structure, made in-house.
- Structural design calculations of the global structure are performed either by an external consultant or in-house. These take different load cases into account and consider structural stability.
- Reaction forces in the nodes are exported from the global calculations for use in connections. The connection type is chosen based on requirements from the architect from a few simple types. (Mostly, internal steel slits are used, since they are non-visible and can carry large loads.) Each connection is then designed using to an excel sheet, or by hand calculations, or in the software Timcon. In rare cases the connection calculations influence the global calculations, for example in deformation calculations of trusses with many nodes; in that case, the slippage of the nodes must be accounted for in the global structure.
- All calculations take place in 2D. Not even complicated connections are designed using 3D software, since the level of difficulty and the time it would take are too great.
- Drawings for the connections are produced independently of the calculations, in Autocad or in Tekla. From these drawings the connections, or their fastenings, are produced in a CNC-machine, with the coordinates put in manually, or by using a circle saw and drills. Finally, the materials are delivered together with steel details and drawings to the construction site.

2.5.2 SYSTEMATIC INITIATIVE

For one of the most common typologies produced - large timber halls - a sort of systemizing software has been developed. Its purpose was to offer customers a fairly accurate view of the cost of the project and its inputs include measurements, cost limitations and climate conditions. The results consist of a chosen type of hall (responding to certain conditions), proposed dimensions, drawings and the required amount of materials and total cost. [Lindgren, 2013]

2.5.3 COMMENTS

The design process of Martinsons AB can be described as a linear one (Fig 2.13): the results of one phase are checked according to criteria exclusive to that phase and then exported to the next. This means that discovering mistakes, made in the beginning of the process, becomes expensive later on, since everything after that point may need reevaluating. This makes the process vulnerable for change to the design. In fact, Lindgren stated that being able to import local connection results back into the global stage would be a great improvement for the design process. In that way a more general analysis would be carried out at an earlier stage, thereby minimizing later changes.

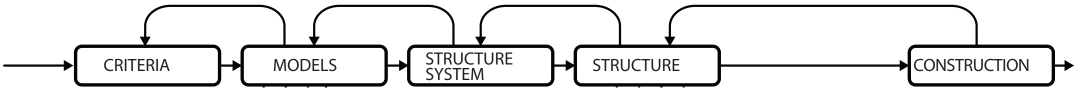


Fig 2.13 *Existing process is linear with clearly separated steps and any changes to the original input is effectively a step backwards as it causes need for another software conversion. [Nordström and Orstadius, 2013]*

That the calculations are all carried out in 2D must certainly lead to conservative design. However, although material is expensive, it is still considered economically preferable to carrying out complicated 3D calculations. Also, the global design takes place before and independently of choice and sizing of the local connection. This leaves little flexibility in terms of adjusting the connections to redistribute the global force, something that can be crucial for the performance of complex structures.

The lack of conceptual analysis tools prevents Martinssons to take every structural idea through the whole process to a final product. Because of this, an early conservative decision is taken to safeguard against later changes.

However, the “job estimate program”, or systemizing software is an interesting development. This can actually be described as a parametric design tool, as it combines input and constraints into a variety of potential results, albeit a very limited number (in this case, 8 different types of halls). It is a form of what Buri and Weinand [2011] call global tessellation, where drawings for different variants of a global structure are produced, without more effort than it would take to make just one. For this to work for a wider array of projects, the approach needs to be generalized, but the intent is the same: to create a flexibility and freedom within the confines of production and performance. One could say that the intention of this thesis is to investigate how this method can be applied in more general cases.

2.6 NEW OPPORTUNITIES IN THE PRODUCTION OF TIMBER STRUCTURES

As discussed in the Section 2.1, the access to different tools determines the complexity of the structures produced. In this section the current and coming production conditions for digitally fabricating complex structures in wood are explored.

2.6.1 WOOD AS A MATERIAL FOR DIGITAL PRODUCTION

With a standardized production, the irregularities of timber and the grading it requires in order to meet certain standards reduced its attraction as a high-performing construction material. [Buri and Weinand, 2011] With the increasing manipulation of the material, in different composites and engineered wood products such as glulam, physical properties can be more reliably predicted. CNC-production makes complex geometries efficiently producible in wood and wood-on-wood connections can now be created that are both structurally possible and economically viable [Neumann and Schmidt, 2007], creating new opportunities for using timber as the primary structural material.

Fig 2.14 *Images from study visit in Weinand's studio at IBOIS. Timber is used to create innovative structural forms and large scale physical testing is conducted to verify digitally modelled ideas. [Nordström and Orstadius, 2013]*

2.6.2 TIMBER AS A HIGH-TECH MATERIAL

In *Techtonics of the timber age*, Weinand and Buri suggest that timber is "taking on the status of a high-tech material" due to its "easy machinability", i.e. its potential of being modified both in terms of geometry and material properties [2011]. The anisotropy of wood produces a very low resistance to stresses perpendicular to the grain, which makes the material difficult to detail from a structural perspective. But it also creates an elasticity and flexibility that can be turned to an advantage using unconventional structural ideas, such as the bending and weaving in the work of IBOIS (Fig. 2.14). Wood is also comparatively light - thus more environmentally friendly to transport - which makes prefabrication more beneficial.

2.6.3 CURRENT EXAMPLES ABROAD

For this thesis, study visits to ETH and IBOIS were informative about the latest developments for using wood as an innovative building material. In experiments at IBOIS, a wooden braided structure had been built as a full-scale prototype and was being tested for deformation (see Fig 2.14). The deformation results were used to inform the shape of the structure. [Weinand, 2012] The experiment was reminiscent of the ICD/ITKE pavilion (presented in section 2.1.4), where deformation data was used for modeling the pre-stressing in a parametrical manner [Fleischmann and Menges, 2012]. These examples propose new ways of modeling and constructing wood and though far from readily applicable, they still shed new light on possible developments for the material. (They also highlight the importance of not getting lost in a digital model when working with structural systems, but to reinforce all hypotheses with physical models of different scales.)

This research also included a study visit at Stora Enso's facilities close to Graz, in Austria, where the market for cross-laminated timber is much larger. No photographs were allowed in the facilities, which were larger than those of Martinsons and featured less manual work. The most important difference was the last step of the production process, which was fully automated here. The wood components were transported to CNC machines, where manufacturing drawings were digitally translated into cutting coordinates. The elements were then cut at equal speed irrespective of their similarity to each other.

2.6.4 INVESTIGATING CONDITIONS FOR DIGITAL PRODUCTION IN SWEDEN

Two study visits were made to Martinsons production factories. The facilities are spacious and well organised and the largest focus is on refining wood products. Focus for the visits were on the final refining of the wood components, the geometrical modifications.

The production of “raw” glulam beams turned out to be nearly automated (see Fig 2.15), but a large amount of manual work remain for modifications; sawing, drilling etc. The digital tools - such as a 3-axis CNC-machine - are not used to maximum capacity. At the time of the study visit, coordinates were put in manually to recreate CAD drawings (rather than setting up an automated digital transfer of information) and this quickly becomes time-consuming for more complex projects. Naturally, this is limiting in terms of what type of projects can be produced, since the cost and effort of manual input quickly becomes overwhelming and there is a large benefit of producing several elements that are identical and can use the same coordinates.

To draw a parallel to Schindler’s categorization (as discussed in chapter 2.1) the current production process seems located at the height of the machine-tool era, where certain types of elements are efficiently produced. Costs are cut by standardizing not only the production processes but the typologies produced and “irregular” projects increase the workload dramatically.

Martinsons’ development focus has been on creating wood products that can rival concrete and steel for reliability and structural performance. The introduction of digital tools has not been prioritized, partly because the demand is not sufficient to justify the initial time and cost investment. However, there is interest, especially as the tools are already present.

2.6.5 CONCLUSIONS

The equipment at the end of the productions chain determines what kind of product is efficient to produce. If tools that can handle digital input are used, there is no noticeable loss of efficiency in producing individualized components. However, if manual input is used, the complexity of the project becomes the determining factor, to the point where some projects cannot be produced because it is impossible to finance the time it would require.

Fig 2.15 *New glulam and japanese wood products in the production line at Martinsons factory in Bygdsiljum [Orstadius and Nordström 2013].*

3.THEORY & METHOD

The theory is focused on proposing a parametric design process, presented as an alternative to Martinsons'. The method is to investigate if this new process is feasible through four examples.

3.1 PROPOSED WORK FLOW OF PARAMETRIC DESIGN

As described by both Engel and Lindgren, the design process of a structural system is built up by several subsequent stages connected with feedback loops, see Fig. 2.13 [Engel, 1997].

These loops can be described as an evaluation process based on the criteria set up at an earlier stage. Often a structure is modeled in a CAD software and then imported into separate analysis programs for evaluation of structural capacity, environmental performance and so on. Arriving at the optimal solution is a matter of testing multiple options and if the model needs to be exported back and forth between different platforms, this quickly becomes time-consuming.

In order to understand how an integrated parametric platform changes the nature of this design process, parametric design must be more elaborately explained.

3.1.1 PARAMETRIC MODELLING FOR GENERATING GEOMETRY

As explained in Section 1.1, a parametric model consists of inputs that are manipulated by operations, which create outputs in the form of generated geometry. A simple example of a parametric method is the creation of ten boxes with a different sizes. In a normal CAD environment this could be generated by drawing the ten boxes one at a time with different line lengths or, slightly faster, generate one box and the copy it ten times and later scale it to different sizes. In a parametric environment the boxes could be generated by specifying the coordinates for the corners of the box and then generating lines between the corners. By including a command that scales the box based on, for instance, the y-coordinate of midpoint of each box, the boxes then become larger when being placed further away in the direction of the y-axis.

This type of modelling has two obvious advantages when generating geometry. The first is the ability to change the produced geometry. By changing inputs, or adjusting the defining rules, a new or changed geometry that adheres to the same rules as the original one is instantaneously generated by the computer without the need for redrawing each part.

The second advantage is the ability to generate multiple variations of local geometry to add up to a global structure. Complex structural systems, such as space trusses, are based on multiple variations of a local structural member which is adopted to its position in the structure. Created in a parametric environment, these become multiples of a generalized element which varies with its position in the structure (see examples in chapter 4). Instead of manually modelling all of the geometry elements, the different components can be defined by their interrelationships in terms of distance or size. These relations stay the same even as specific measurements are modified.

3.1.2 THE LANGUAGE OF PARAMETRIC DESIGN

Defining rules and relationships can be done in various ways, but always involves some sort of programming. Writing a code to generate a point in space in a 3D CAD program is complex if done from scratch, but luckily in different languages a library of commands already exists. Generating lines in a parametric platform simply requires definition of two coordinates which defines the start and end points of the line generating component and by combining more geometry-generating components, increasingly complex forms can be drawn. Grasshopper, the tool used in this thesis (more detailed description in Chapter 3.2.1) is high up in the hierarchy of coding, which means that it it has a well-developed interface and consists of clusters of commands with inputs and outputs, rather than individual commands. When building geometry, the list of commands remain on screen and this becomes what is referred to as the *parametric definition*.

3.1.3 PARAMETRIC DESIGN AS A COMMUNICATION TOOL

Since the output model changes with changing input, a parametric model can be used to directly evaluate versions and results of a specific geometry, making it a useful tool for communicating design iterations (se Fig 3.1).

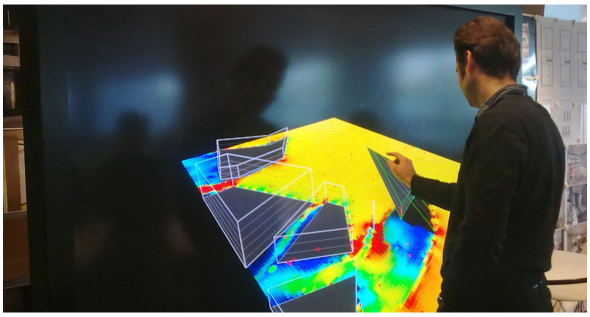


Fig 3.1 *Displaying a parametric communication tool [Foster + Partners, 2013].*

3.1.4 PARAMETRIC DESIGN AS ANALYSIS TOOL

In a parametric environment, geometry can be simultaneously generated and analysed. Extracting information about the model, such as its dimensions, is done by simple commands in the code and this information can be fed into analysis tools simultaneously with generation of new geometry. Examples of topics for such analysis are wind patterns, energy use, light intake and structural efficiency.

3.1.5 PARAMETRIC DESIGN AS MULTI-OBJECTIVE

OPTIMIZATION TOOL

When using a multi-objective solver in a parametric environment, different input data are combined and automatically evaluated to find the optimal set for the given weight-function [Rutten 2012]. Different sets of input values are applied and the fitness of their outputs ranked according to a specified criteria. Multi-objective solvers can be programmed in various ways, but the objective is optimization. (For structural optimization, types of optimization include topology optimization, size optimization or shape optimization [Sehlström, 2013].)

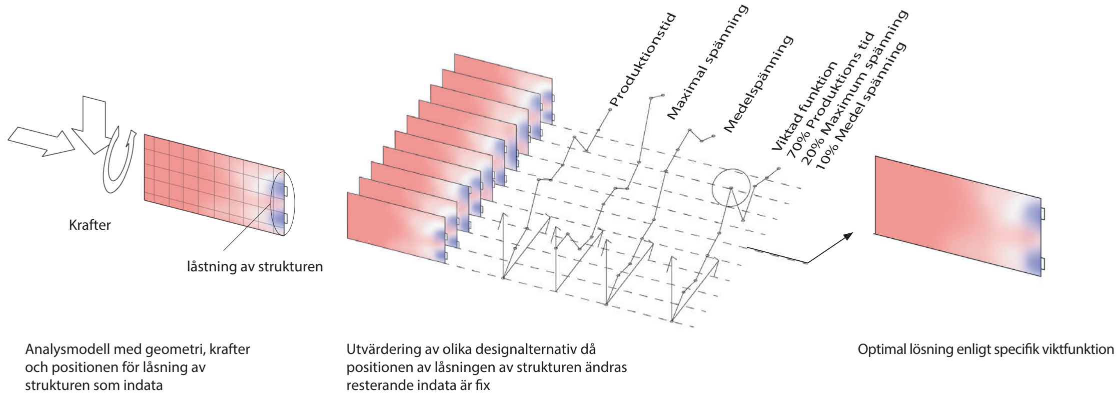


Fig 3.2 *An example of a situation which is easily evaluated using multiple objectives [Nordström and Orstadius, 2013]*

3.1.6 SUMMARY PARAMETRIC DESIGN

Parametric design holds a lot of potential as a communication and sketch tool, geometry generation, analysis and optimization can take place in a single environment that can be used in different professions. The potential is especially high in the early stages of design, where there is freedom for many design parameters to affect the design. It is especially beneficial that different criteria can be weighted and the design analyzed according to several objectives. The ability to change and adjust the geometry with updated indata is greatly preferable to redrawing the whole geometry. It is also an ideal tool for a structure with repetitive elements (which often is the case in complex structures).

One drawback to parametric modeling is the extra time it takes to set up the definition, compared to modelling it in a CAD environment. This is especially true if the geometry is hard to describe mathematically. Another disadvantage is the extra knowledge it takes to set up a parametric model compared to a regular 3D model.

3.1.7 CONCLUSIONS DESIGN PROCESS

The very systematic process described by Engel (see Fig. 2.12) has little space for design iterations. Each piece of revised information risks a revision back to an earlier stage, perhaps at great cost and inconvenience, which decreases the inclination for experimentation. Similarly, Martinsons' process - though streamlined and efficient for the most common typologies - is ill suited for redesigning and testing multiple solutions and "one-of-a-kind" buildings with special requirements.

A parametric design model (Fig. 3.3), on the other hand, is an excellent fit for testing different structural concepts in a fast, accurate way. This work-flow shortens the feedback loops and the overall design process. It requires some extra knowledge and is time consuming in early stages, since the work load shifts to earlier in the process, but the reward is a more general way of modeling variations on a structural concept that all fit the criteria defined early on.

In a parametric definition, a structural system is defined rather than a single structure. This model generates the geometry, can incorporate analysis in different scales and can be optimized according to any quantifiable criteria. The output, the specific structure, is simply one variation of that structural system. The production and construction restrictions, as well as the evaluation of different structural concepts, apply to the defined structural system rather than the structure.

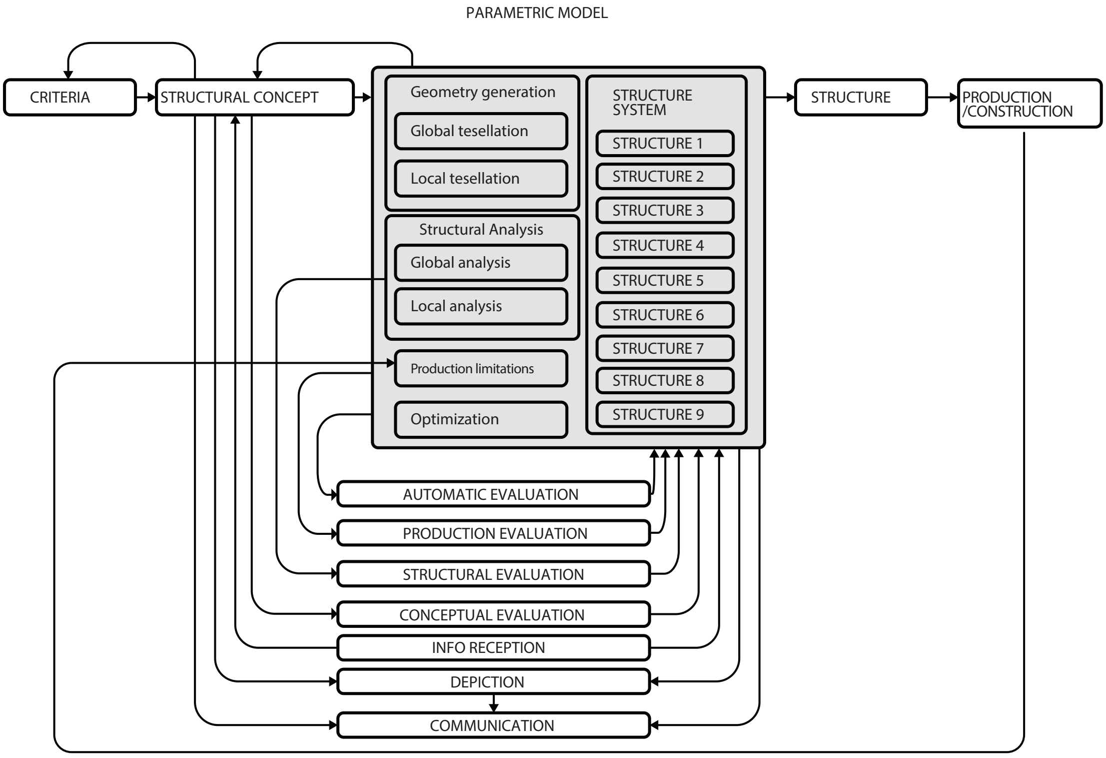


Fig 3.3 *A schematic parametric design process. The structure is one version of the structural system designed and all modifications are handled at an earlier stage than in a regular process, incorporated in the parametric model either natively or as external plugins [Orstadius and Nordström 2013].*

3.2 IMPLEMENTATION OF PARAMETRIC WORK FLOW

The intention is to test this parametric design process in different scales, specifically in situations where a software conversion would be needed in a standard design process.

3.2.1 TOOLS: GRASSHOPPER AND RHINOCEROS

The parametric platform used in this thesis is Grasshopper (see Fig. 3.4), a plug-in to McNeel's NURBS-based 3D-modeling program Rhinoceros 3D. It is the most commonly used program for parametric modelling and is most popular with architects, since it i possible to use without extensive programming knowledge. Its generality makes it quite powerful. It also has the benefit of having a simultaneously geometrical representation of the geometry generated in the code.

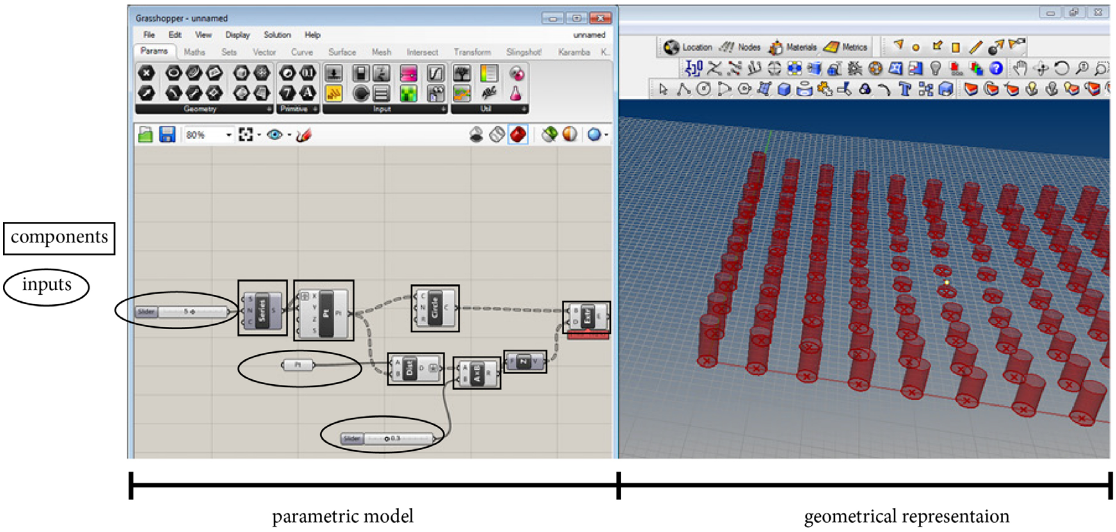


Fig 3.4 *Example of the Grasshopper interface and the geometrical representation of an algorithm [Orstadius and Nordström 2013].*

In this environment, a model can be defined using components. Each component is contains several programming commands which together perform mathematical operations or representation of geometry. (This is analogous to the drawing software AutoCAD, where written commands can both create geometry such as a line and perform operations on that geometry, such as rotation.) By connecting the components to each other (showed as wires in Fig. 3.4) a model is formed and a representative geometry is generated which is updated live once the input values or commands are changed.

The script in Fig 3.4 starts with a component which creates a series of values from three given in data, startnumber, stepsize and number of values. The secound component creates a point in the 3d space of Rhinoceros from three coordinate values, those coordinates are given from the first “value creator” component. From these points pipes with different length are created from several other components resulting in the geometrical result showed in the right side of Fig 3.4.

Grasshopper can also import static geometry from Rhinoceros and return geometry back to Rhinoceros after processing it in the definition (using the “bake” command). Grasshopper is a free software and its popularity has spawned various plugins that can handle different issues of modeling and analysis.

3.2.2 EVOLUTIONARY SOLVER GALAPAGOS

Galapagos is an evolutionary algorithm designated to solve single- or multi-objective optimization problems within Grasshopper. As the developer David Rutten explains in his blog “I Eat Bugs for Breakfast” [2012], numerical inputs are set as genes, weighted and combined in a number of permutations. The resulting outputs are then automatically evaluated according to its fitness or closeness to the goal. In structural analysis, the input genes could be weight of the structure, cost and volume and the desired output could be a low stress in a defined point.

The process can be described as a fitness landscape with the y and x axis representing two parameters or inputs in the code and the z-value of the landscape is the fitness value for the combination of the two parameters (see Fig 3.5). As the name indicates, the evolutionary algorithm solver works in generations, where the first generation is created with random combinations of the parameters. The next generation is created from the fittest individuals from the first generation and so the process repeats.

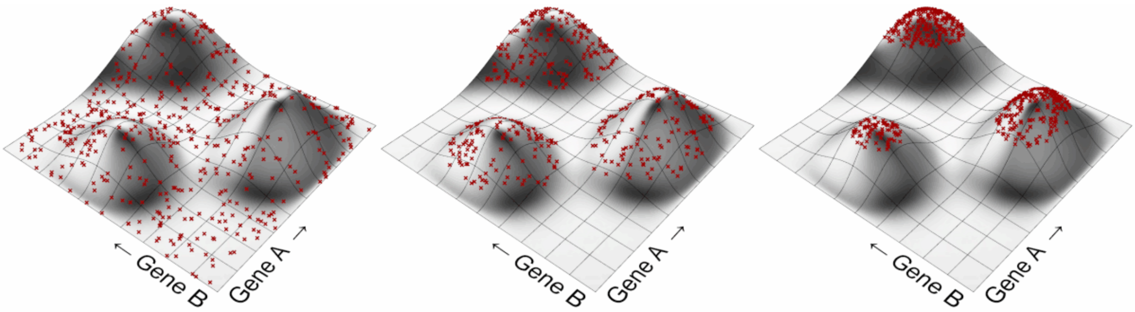


Fig 3.5 *As generations progress in Galapagos, the maxima of the fitness landscape is increasingly populated, meaning that the optimal solutions are approached. [Rutten, 2012]*

Evolutionary solvers are slow, but they are well suited for problems with many different variables and ”remarkably flexible” [Rutten, 2012]. They require a well-defined problem, fitness function and specific desired output.

3.2.3 LINKING STRUCTURAL ANALYSIS TO PARAMETRIC DESIGN

According to Mirtschin, “to maximise the benefits offered by generative modelling, present manual coordination of independent models should be minimized” [2011]. At the moment several developers are creating links between Grasshopper and structural FE analysis software, opening up for possibilities of combining parametric modelling with structural analysis. This is especially useful for well-defined problems such as optimizing advanced structures to minimise material usage (for example through form finding).

These analysis programs can inform the Grasshopper geometry with material properties, such as Young’s modulus and density. An objective of letting the structural analysis influence the geometry can be to optimize the material distribution, so that components are tailored for stress concentrations, for instance “solving” for a structure that works primarily in axial forces for the most material-efficient handling of loads [Olsson, 2012].

3.2.4 OASYS GSA: STRUCTURAL ANALYSIS IN GRASSHOPPER

The original software OASYS GSA was developed by engineering firm ARUP to handle complex structures and create a “comprehensive design program” [OASYS, 2013]. It is widely used today by engineers; Expedition Engineering used the program for analysis for the double-curved textile roof for the London Velodrome of the 2012 Olympics [Mirtschin, 2011].

A recently created plugin to Grasshopper developed by programmer and structural engineer Jon Mirtschin lets the FE analysis communicate with the geometry generated in the parametric platform. It exports the geometry to the GSA program which runs simultaneously with Grasshopper and later imports the result back. The software can handle both 1D and 2D elements. It can also be combined with Galapagos to let the computer optimize the geometry according to the set up fitness function (see Fig 3.5).

GSA requires a version of the program to run outside of GH (see Fig. 3.6), which requires a large amount of processor power. One limitation of the program is that it can only handle shell structures, not solids, which raises the question of how to approximate a 3D phenomenon correctly.

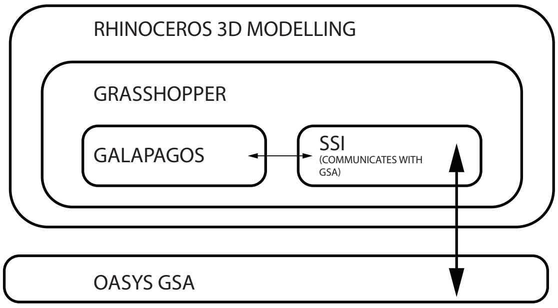


Fig 3.6 *The relationships between the programs. [Nordström and Orstadius, 2013]*

There are very few examples exhibiting the connection between Grasshopper and GSA. One of the few is a Master's thesis by Michael van Telgen, which discusses optimization of a steel truss bridge with GH and GSA [van Telgen, 2012]. The example treated in this thesis is shown in Fig. 3.7.

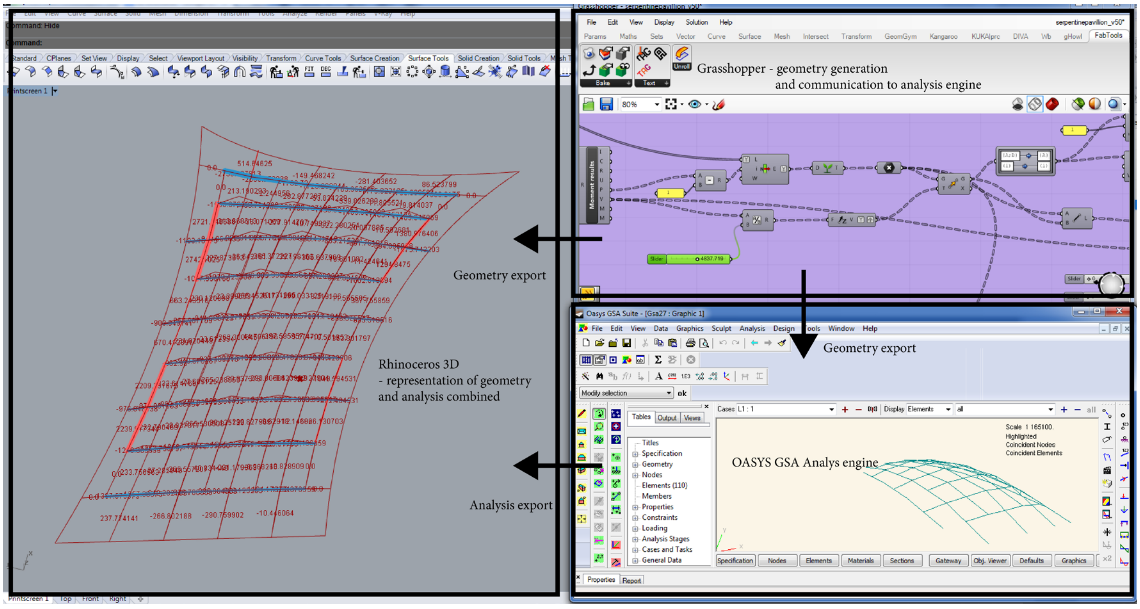


Fig 3.7 *An example combining Grasshopper with GSA to look at the force distribution in a complex structure [Orstadius and Nordström 2013].*

4. SUB PROCESS TESTING

In order to explore the parametric environment and design process, a series of excerpts of the process have been tested.

First, a reference structure from Appendix A is modelled parametrically. The objective of incorporating structural analysis to a parametrical model is explored. A more in-depth study of another complex timber structure is conducted. Its structural system is analysed and different iterations of it are tested in order to understand how different global forms affect the magnitude of the forces within the structure.

Finally, in order to really understand the benefits and drawbacks of a parametric process and the difference it makes at an early stage of the project, it is implemented into the design of a small pavilion, influenced by production information obtained in section 2.6.

4.1 PARAMETRICAL SYSTEMIZATION OF A COMPLEX STRUCTURE

Purpose

The model (Fig. 4.1) explores the understanding the geometrical and structural patterns of a structural system required in order to express it as an algorithm and generate the geometry parametrically. In Fig. 3.3, it treats the section "Geometry generation". It is necessary to determine what needs to vary in the system, i.e. the input and the desired output.

Procedure

The Oguni Dome is a space truss (a vector-active structure, according to Engel [1997]). Its bars fix points in space, which means it is structurally stable as long as its pattern is complete, irrespective of what shape it has.

Keeping the shape general - i.e. permitting global tessellation (distinctions between individual iterations) - is the core of the parametric model. The definition of the structural system is based on a surface, where points are distributed regularly to form a grid. The points are then moved in the normal direction to the surface in that point, so that a structural depth is acheived. Then the points are linked together to illustrate the bars that stabilise the two layers against each other. The surface can then be modified and form new global shapes without the structure losing stability (although the structural depth must be reconsidered).

Result

The resulting model (Fig. 4.2) can be applied to any surface (Fig 4.1-3).

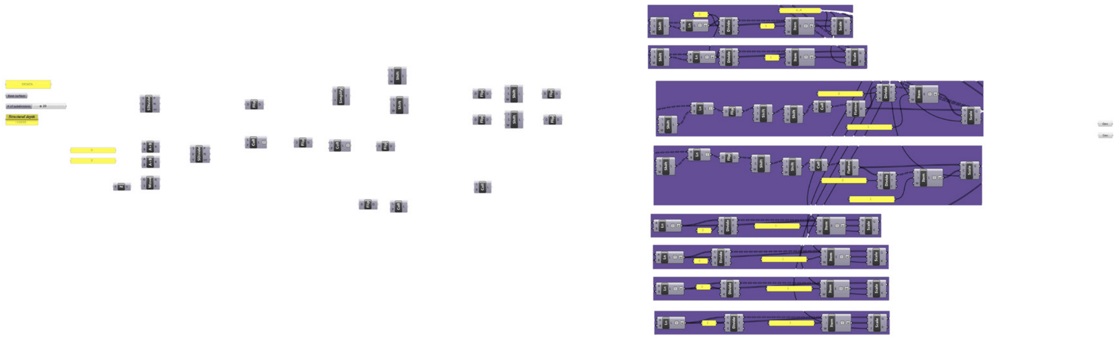


Fig 4.1 *A parametric model of a space truss. [Nordström and Orstadius, 2013]*

Comment

The Oguni Dome is an exhibit of local tessellation - the lines between the points will all be of varying length as the shape shifts. This is cumbersome to model non-parametrically, where the whole geometry would have to be calculated in each point.

More poignantly, when applying the system to a new shape, a non-parametric model would have to be redrawn completely. This is a strong benefit of parametric modelling: to be able to make a general model that can then be used to apply a system to different base components (inputs). It is easy to see how this would be beneficial in early stages of a project, when perhaps a general system is decided on but the shape is not fixed. If the definition of the structural system is written generally enough, it can be used to portray a vast array of structures.

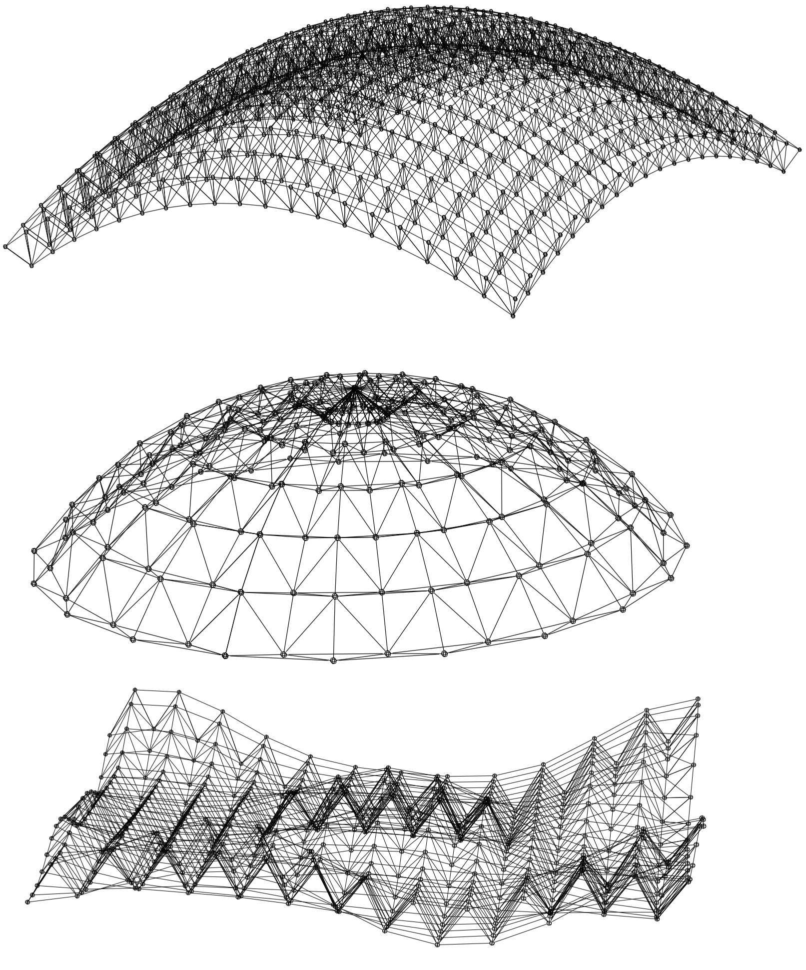


Fig 4.2 *Here, the same parametric model is simply applied on different surfaces, creating different shapes. The code is written generally enough that the structural system could be applied to various shapes. [Nordström and Orstadius, 2013]*

4.2 STRUCTURAL ANALYSIS AND OPTIMIZATION

These processes were used to evaluate the combination of Grasshopper, GSA and Galapagos.

4.2.1 MINIMIZATION OF STRESS IN A HINGED PLATE

The test was conducted to investigate the function and potential of the GSA plugin to Grasshopper and its native evolutionary algorithm Galapagos. Local analysis and optimization are explored (see Fig. 3.3)

Procedure

A simple rectangular mesh was modelled in Grasshopper. GSA components created hinges as boundary conditions on the lefthand side, simulating a consol, while a constant force was applied downwards on the right-hand side. Then the two positions of the hinges were varied along the y-axis to see which combination of two hinges would produce the lowest maximum stress in the mesh (Fig. 4.3). The position of the hinges were defined as input in Galapagos and the maximum stress was the result designed to be minimized.

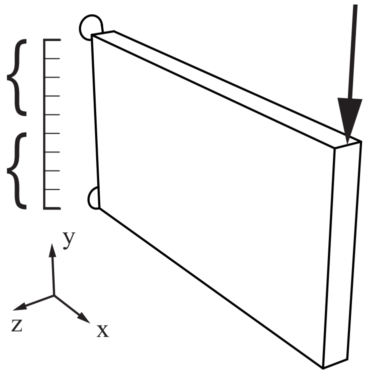


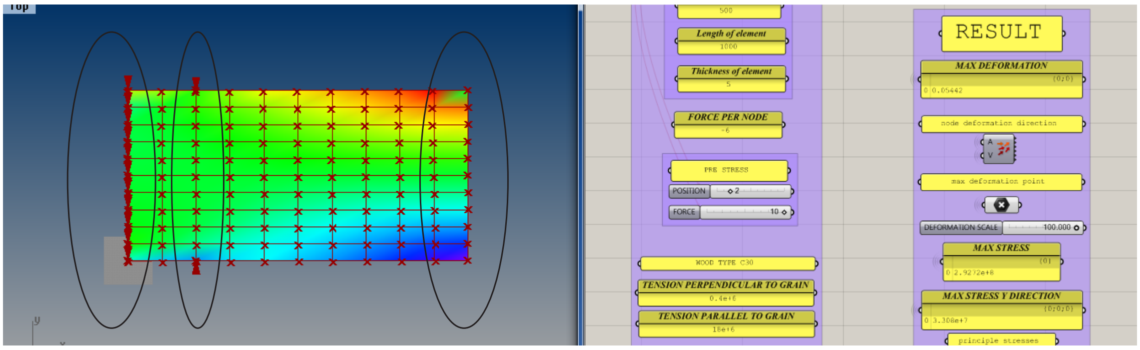
Fig 4.3 *The positions of the hinges in the y-direction are changed to find the lowest stress. [Nordström and Orstadius, 2013]*

Hypothesis

The expectation was that hinges placed in the outermost corners of the mesh would produce the minimum stress, since this would produce the lowest moment possible around the attachments.

Result

The resut was as expected, after a fairly fast run (see Fig. 4.4). Some communication with the plugin developer Jon Mirtschin was needed to correct bugs, such as a tendency for the mesh to "remember" the previous result instead of updating. Once that was cleared up the plugin was judged reliable enough to continue using.



500

Length of element
1000

Thickness of element
5

FORCE PER NODE
-6

POSITION 2
FORCE 10

WOOD TYPE C30

TENSION PERPENDICULAR TO GRAIN
0.4e+6

TENSION PARALLEL TO GRAIN
18e+6

MAX DEFORMATION
{0;0}
0 0.05442

node deformation direction

max deformation point

DEFORMATION SCALE 100.000

MAX STRESS
{0}
0 2.9272e+8

MAX STRESS Y DIRECTION
{0;0;0}
0 3.308e+7

principle stresses

Fig 4.4 *Screenshot of the FE-mesh for the hinged plate. To the left are the parameters that can be changed. [Nordström and Orstadius, 2013]*

4.2.2 Y-SHAPED 3D MESH

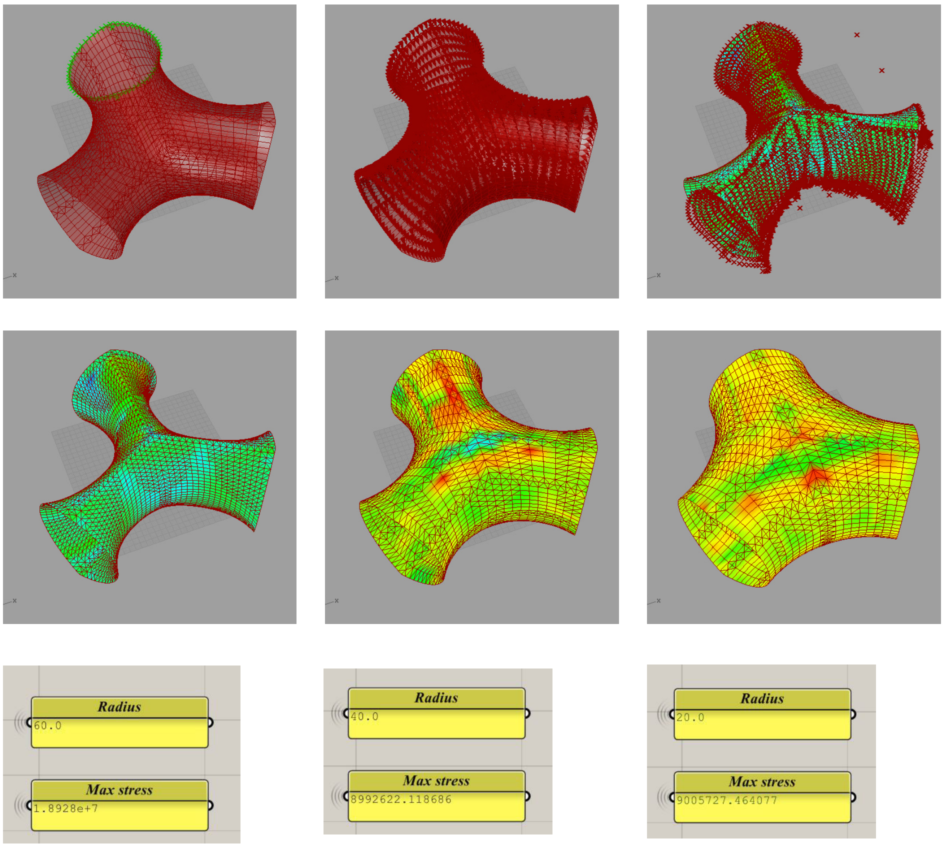
The purpose is to test the form finding ability of the application on more complex 3D geometries (Fig. 4.5). Here, global analysis and optimisation are explored (see Fig. 3.3).

Procedure

A 3D mesh is modelled with varying radius and locked in one "leg" and an outward force is applied to the other two. The radiuses of the mesh are then run through Galapagos until the shape with the lowest maximum stress is reached.

Result

This experiment shows that stress plots could be visualized even on complex, three dimsional geometries and that the parametric model easily can evaluate several variants in a short time. The result of the three options evaluated seemed reasonable, as the lowest average stress was acheived in the option with the most material and least sharp angles.



Radius
60.0
Max stress
1.8928e+7

Radius
40.0
Max stress
8992622.118686

Radius
20.0
Max stress
9005727.464077

Fig 4.5 *Top row: the locked nodes, the applied forces and the displacements, respectively. Middle and bottom row: the stress distribution for three different radii of arches between the legs and the maximum stress in the mesh in Pascal. [Nordström and Orstadius, 2013]*

4.3 COMPLEX SYSTEM STRUCTURAL ANALYSIS

This experiment focused on early stage structural analysis of a complex geometry and the possibility to visualize the consequences of different global forms. This could for example be useful in an early meeting with architects and structural engineers to see the interaction between space and force distribution. The case study for the experiment was the Serpentine Pavilion of 2005, which was designed by Toyo Ito and Cecil Balmond. It employs a Zollinger structural system, which was originally designed to cover large spans while employing smaller pieces of wood, and where each element is bisected by the meeting ends of two elements that cross it.

The force pattern of the Serpentine Pavilion is quite complex, since it works in bending but its connections cannot transfer moments. Instead, the weaving pattern creates an interaction between the elements that carry the forces. An objective of the systemization is to be able to vary the connections according to the section forces they are affected by. The result is a material efficient structure with a connection that has a repeated function but a varying geometry.

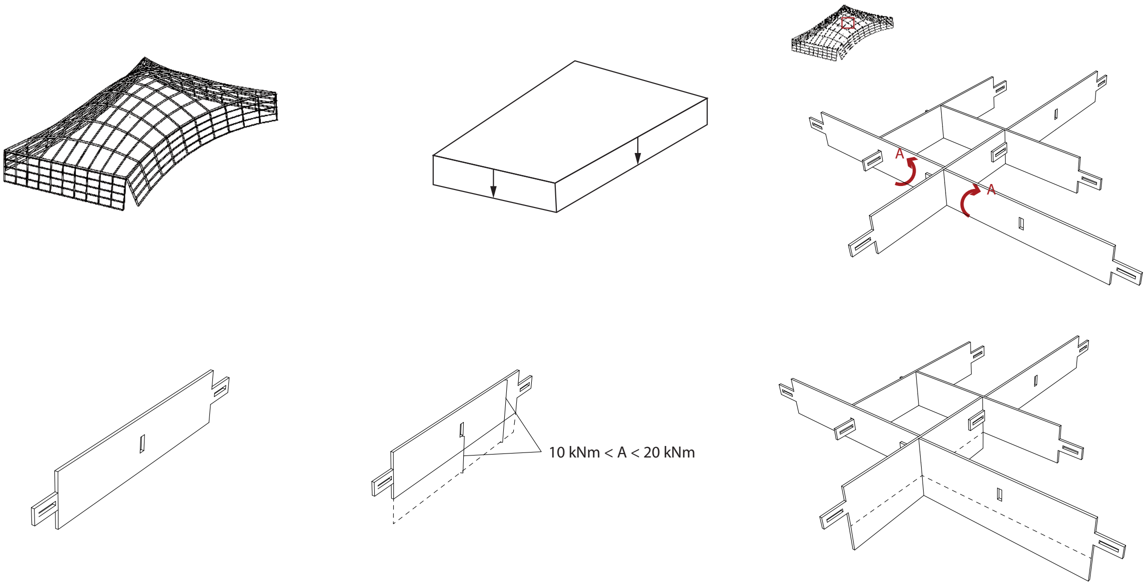


Fig 4.6 *A graphical representation can easily be made of the analysis results from the parametrical model. [Nordström and Orstadius, 2013]*

Procedure

The Zollinger system was defined as a braided pattern, with the ends of elements threaded into the middle of adjacent elements and then extruded. In the model, the connections between elements were approximated as having no rotational stiffness relative each other in the longitudinal direction. This means that the elements can only trasfer moments by translating it across the braids and is on the safe side.

One way to inform the structure and optimize it structurally would be the increase the height of the beams relative to the moment they take (Fig. 4.6). The moments for each global form were thus calculated for each beam and interpreted as heights of the beams.

Hypothesis

A more cupola-shaped global form will show a decrease in axial forces and moments along the elements.

Result

The geometry was challenging to define, with *pinned* connections between elements. Once the structure was defined, however, the definition worked very well. Axial forces and moments could be extracted for variants of the structural system and instantly translated into new beam heights (Fig. 4.7). The displayed result seemed reasonable, with the most uniformly curved surface leading to the lowest moment. A cupola with concave parts created tension along all beams in one direction (Fig. 4.8).

Comments

This test showed the usefulness of modelling a structure parametrically in order to structurally analyse it. A large number of variations of the structural system, that all easily could translate into real structures, were evaluated in a very short time. By just changing the input of the geometry, a new version of the structure was instantly produced and analysed. It was also possible to show the varying section forces graphically in the model, which made the design process more intuitive.

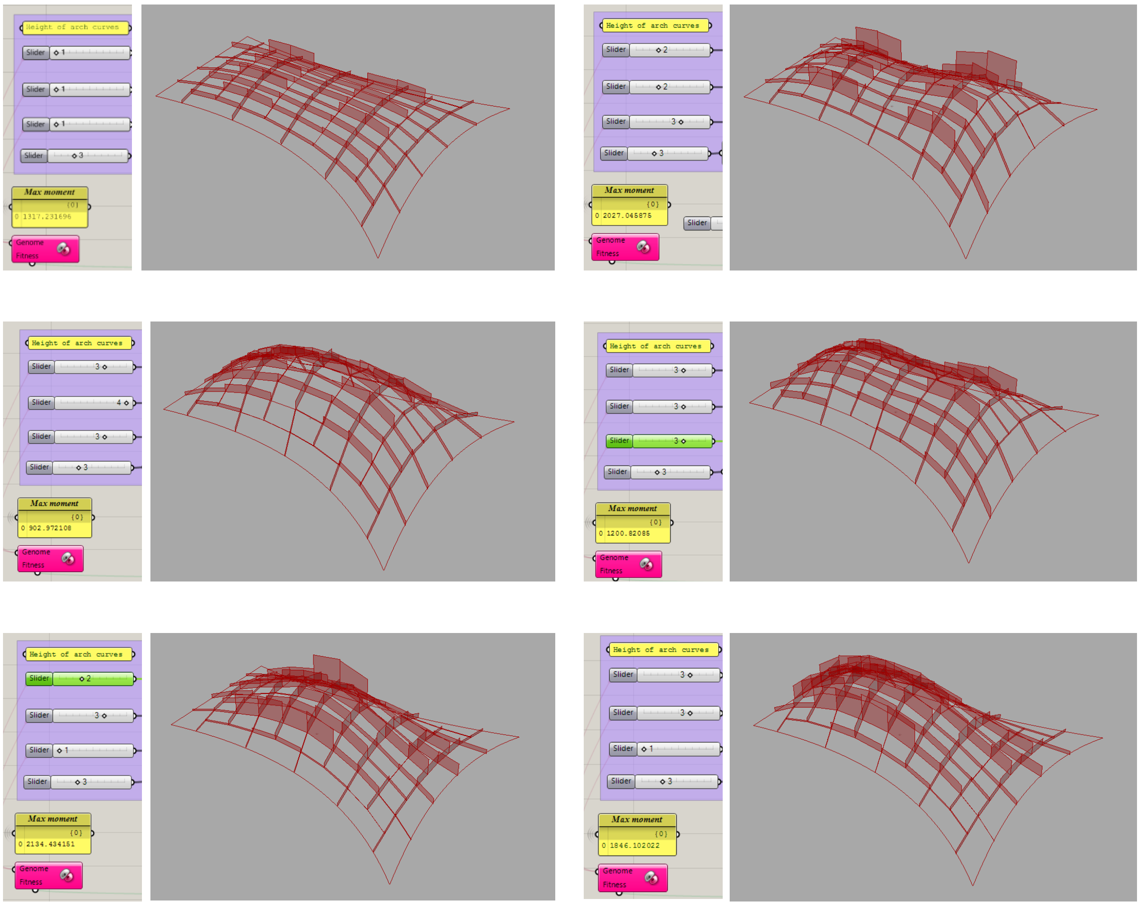


Fig 4.7 *Six different iterations: as the four respective heights of the base curves are altered, the geometry generated changes, as does the moment distribution throughout the structure (illustrated here as height of the beams). [Nordström and Orstadius, 2013]*

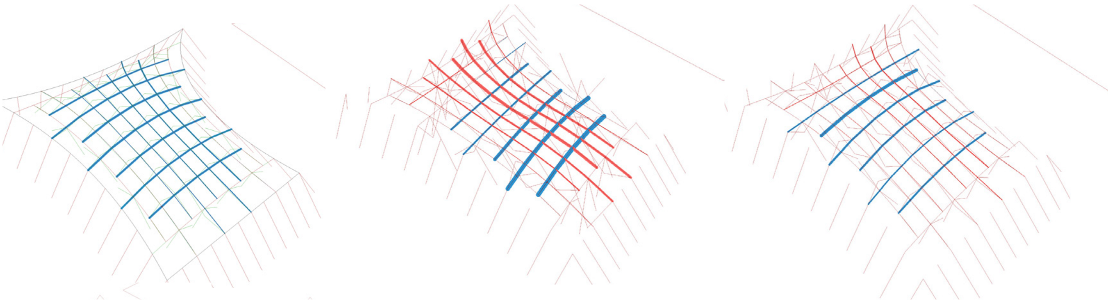


Fig 4.8 *Investigation of the axial forces in the structure. In the iteration to the left, the structure is quite flat, leading to large horisontal forces and thus large axial forces. In the two to the right, the concave areas cause tension, which is propagated throughout the structure - a quite unexpected phenomenon. [Nordström and Orstadius, 2013]*

4.4 PARAMETRIC DESIGN PROCESS OF A STRUCTURAL SYSTEM - FROM FILE TO FACTORY

This experiment is focused on parametric design in a early design phase. How are early choices of a structural system taken into consideration with programmed space and other criteria of the design? How and when is the design process translated into a parametric environment with the possibilities of evaluating different options? How can physical testing and production limitations inform the parametric model? Recall Fig. 3.3: in this test, the whole chain from Criteria to Production/Construction is implemented.

4.4.1 THE PROGRAM

The goal for the design was a pavilion for an exhibition. The initial criteria were:
- creating a small interior space
- creating a freestanding form active structure
- the production was limited to a lasercutter or a 3 axis milling machine
- material to use was 3mm plywood
- construction of the pavilion would take place on site, in a short time, by hand assembly
- no metal joints.

4.4.2 1ST LEVEL OF STRUCTURAL SYSTEM CHOICE: 2D ELEMENTS IN COMPRESSION

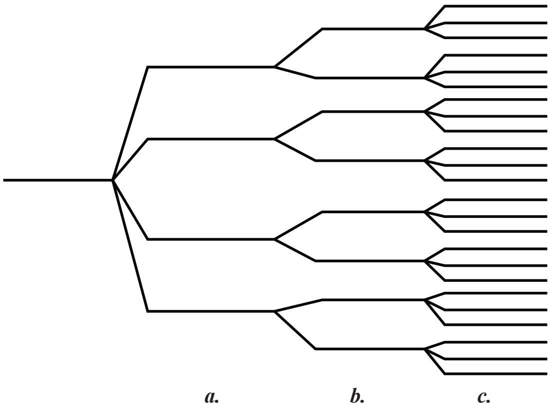


Fig 4.9 *Family of structural systems: a. Limiting the number of branches to work within (recall Chapter 2.3); b. Choosing a more specific system; c. Exploring variants of the chosen system: setting up a parametric model. . [Nordström and Orstadius, 2013]*

After exploring the options of different structural systems that fitted the initial criteria (assuming a form active global structure that worked only in compression), a choice was made to continue work with plate elements, in either a section or surface active structure system. This can be illustrated as a choice between the first "branches" of the structural systems (see Fig. 4.9 - a). One factor in the decision was that 2D elements are an interesting and underused construction component that, as Deplazes [2005] points out, will increase in relevance as production methods advance.

This decision gave following outcome:

- The shear between the different plates made possible a simple connection that works in one line. The structure would have to be geometrically stable, since that connection would be sensitive to bending moment.
- Production is possible in only 2D. Models and mockups can be made with relative ease in smaller scales, aided by laser cutters etc.

4.4.3 2ND LEVEL OF STRUCTURAL SYSTEM CHOICE: ELEMENT CONFIGURATION

From the choice of the first level, two structural subsystems of systems precisely fitted the intentions of the initial criteria; a Zollinger beam-grid system and a system of hexagonal folded plates (see Fig. 4.9 - b).

This evaluation was also made by a general knowledge understanding of the performance of the system. The intention was to find a system, where the connection or individual element determined the resulting global form and performance of the structure. Thus two fairly different systems were sketched and two different global forms were associated with these, in order to find a logic form for the system (see Fig. 4.10). Although the forms where different they both still fulfilled the initial criteria. An important conclusion from this phase in the design process was not to have a too fixed global shape to force the structural system into. The two concepts were also compared more in detail regarding the initial criterias. The choice was to continue working with the hexagonal grid, mainly because of the possibilities of easier assembly.

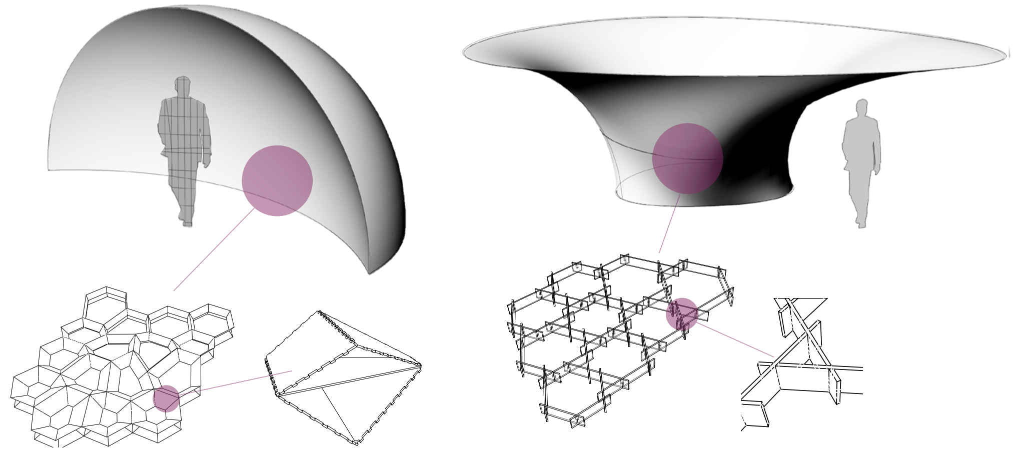


Fig 4.10 *Hexagonal and grid systems were sketched with global forms. [Nordström and Orstadius, 2013]*

4.4.4 3RD LEVEL OF STRUCTURAL SYSTEM CHOICE: PARAMETRIC ENVIRONMENT

Still, infinite variants of the chosen system could be investigated and compared in order to achive a final design (see Fig. 4.9 - c). Now the parametric model was introduced in the design process in order to help out with these evaluations and decisions.

The stage of development in the design process (and the level of the structural system tree) decides how general the parametric model should be (and vice versa). How wide a range of geometry can be modelled with this code? It takes experience to know when to introduce the parametric model into the evaluation process.

In this current design process, it felt logical to introduce the parametric model early on, considering the complexity of the design. A model of the structural hexagonal system was made (Fig. 4.11). This model could be applied to any global form and the number and shape of elements could be changed (Fig. 4.12). Its purpose was to explore the global shape in relation to the components (hexagons). This is the big advantage with having modelled the structure parametrically: once the parametrical definition has been made, many versions can be tested and evaluated in quick succession. The represented geometry and numerical results from the hard parameters - measurements as area, cut line etc can all be extracted directly from the structure - could be evaluated manually and digitally and design judgments could be made based on these (Fig. 4.13).

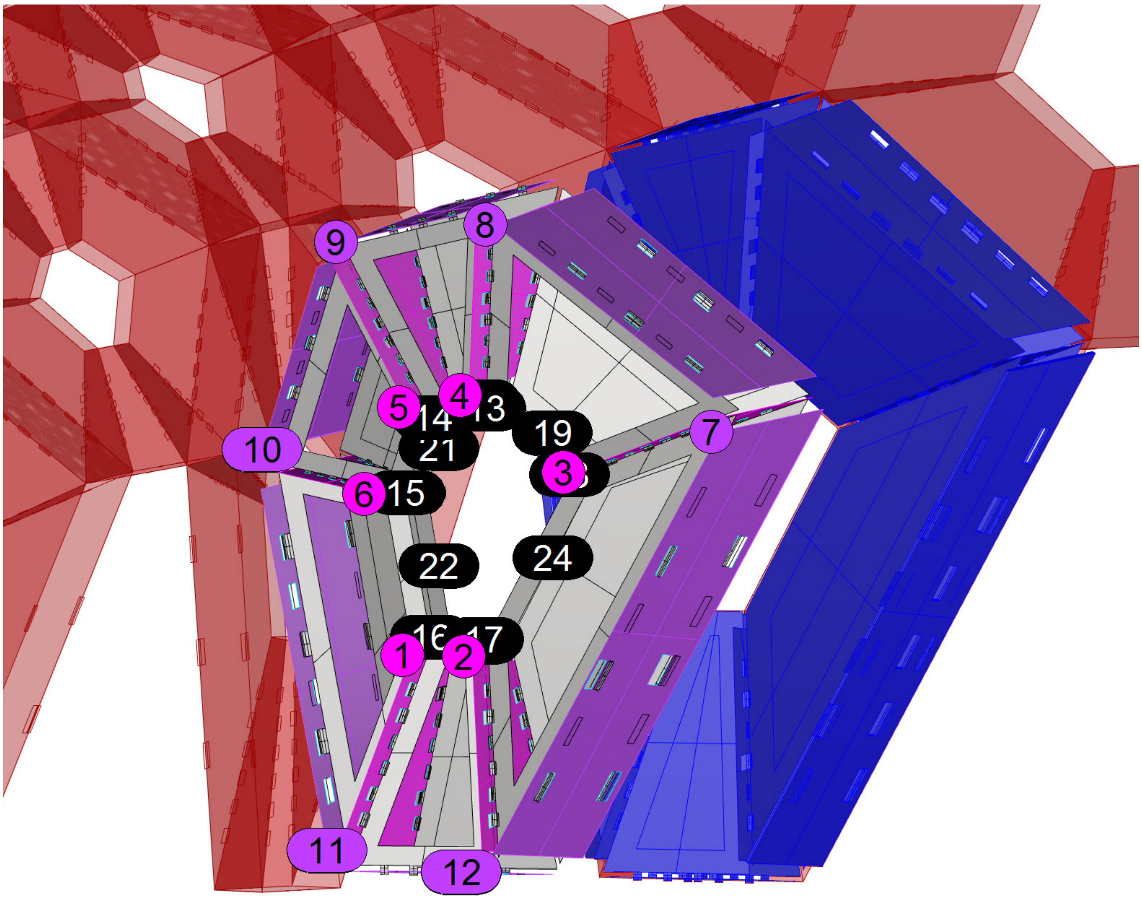


Fig 4.11 *The parts of the developed structural system. It consisted of rectangular elements that were first assembled into hexagon-shaped building blocks (referred to simply as hexagons) that were stable in themselves. These were then assembled into a global form which handled its selfweight only in compression. [Nordström and Orstadius, 2013]*

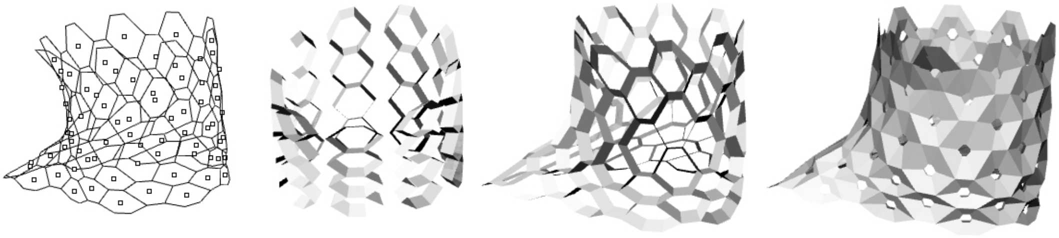


Fig 4.12 *Having set up the parametric system, different forms were explored. [Nordström and Orstadius, 2013]*

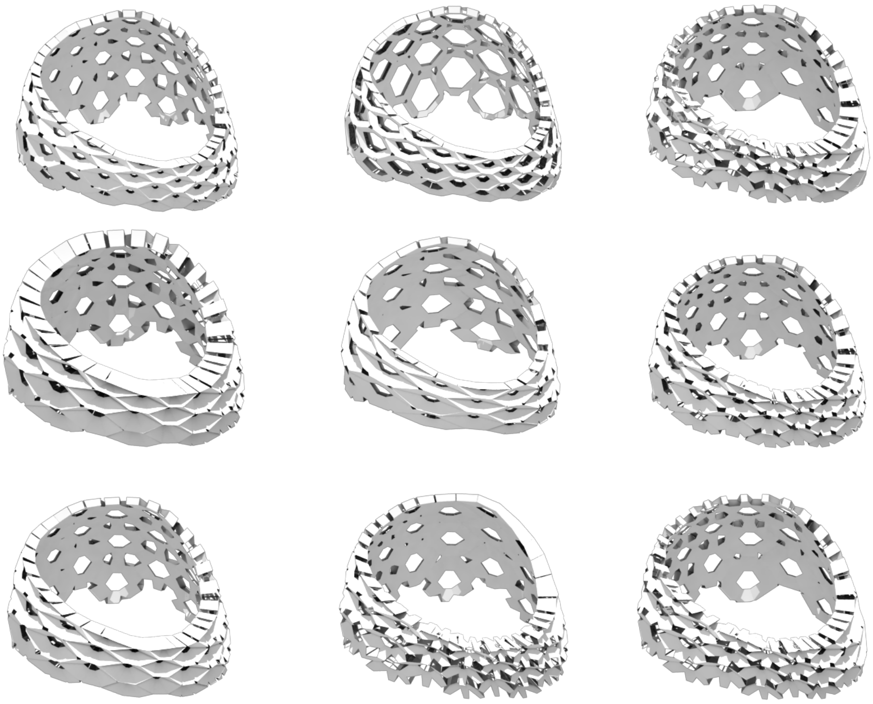


Fig 4.13 *Nine variants of the global form. A more finished global form being finetuned according to parameters such as number of elements and total area. [Nordström and Orstadius, 2013]*

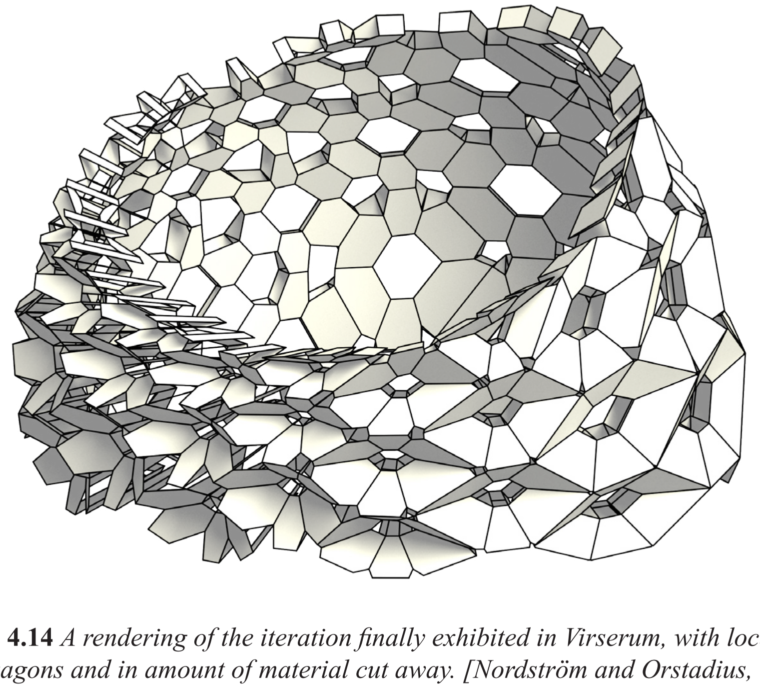


Fig 4.14 *A rendering of the iteration finally exhibited in Virserum, with local tessellation in form of the hexagons and in amount of material cut away. [Nordström and Orstadius, 2013]*

4.4.5 TESTING AND ADJUSTING ACCORDING TO PARAMETERS

In this particular process, the optimization of the structure was done manually until a satisfactory form was reached (Fig 4.14).

4.4.6 DETAILING AND PHYSICAL MODELS IN DIFFERENT SCALES FOR TESTING

Physical models (Fig. 4.15) proved vital for testing whether the definition was complete and versatile. The system needed to be verified, as it can be hard to detect mistakes and problems in a complex structure. It was also necessary to keep in mind the relationship with the physical material and test how its properties affect the different scales in the structure.

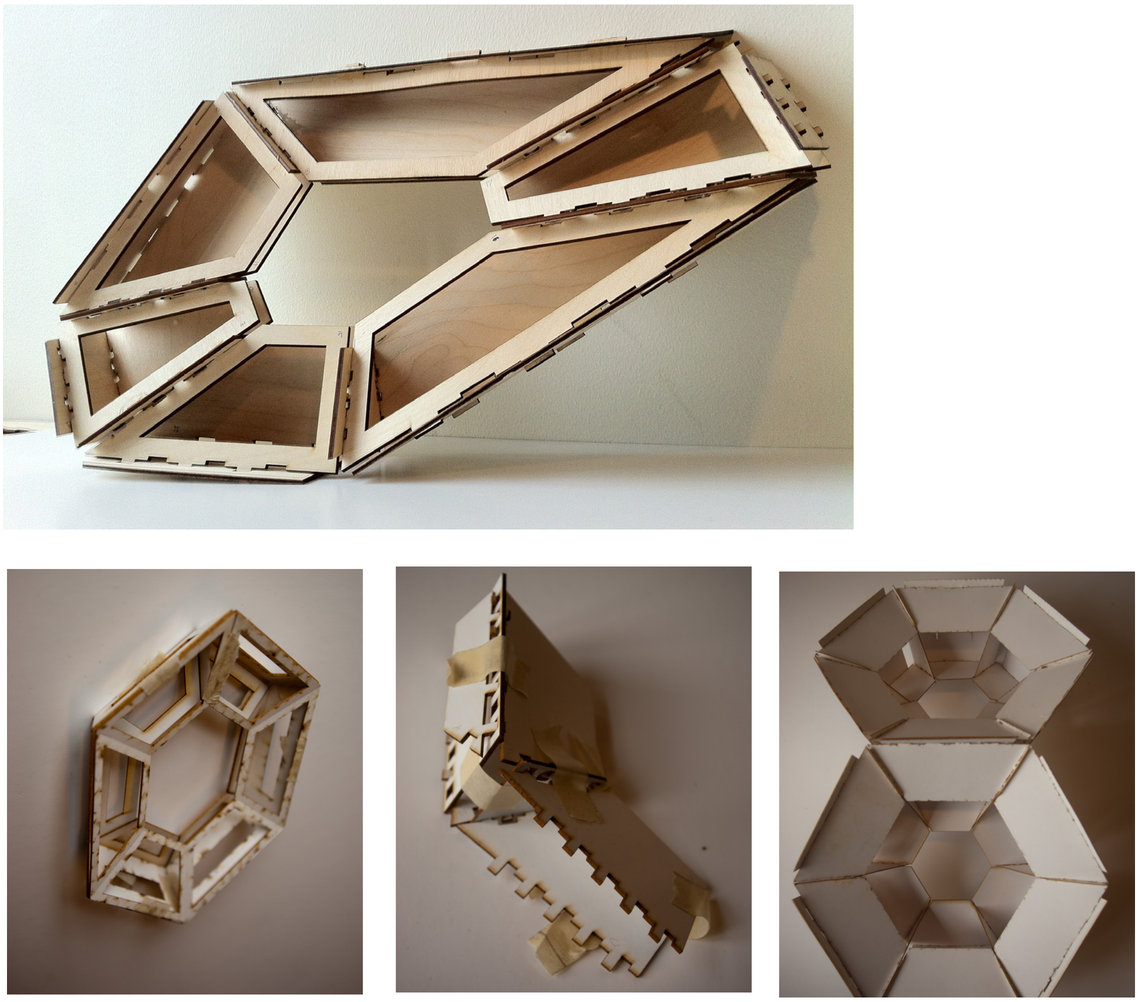


Fig 4.15 *Process models to test different aspects of the structure. [Nordström and Orstadius, 2013]*

The physical model work was done simultaneously to the digital in order to verify the result. In this way, a final version of the pavilion was decided upon. This version fulfilled criteria of form and was possible to produce.

Specific things to test in this structural system included:

- Flexibility of plywood. Simple bending tests of the plywood were conducted (see Fig. 4.16) and the results were implemented in the code. The bending flexibility affected how far the holes should be shifted relative each other at a 90 degree angle to the edge of the plate.

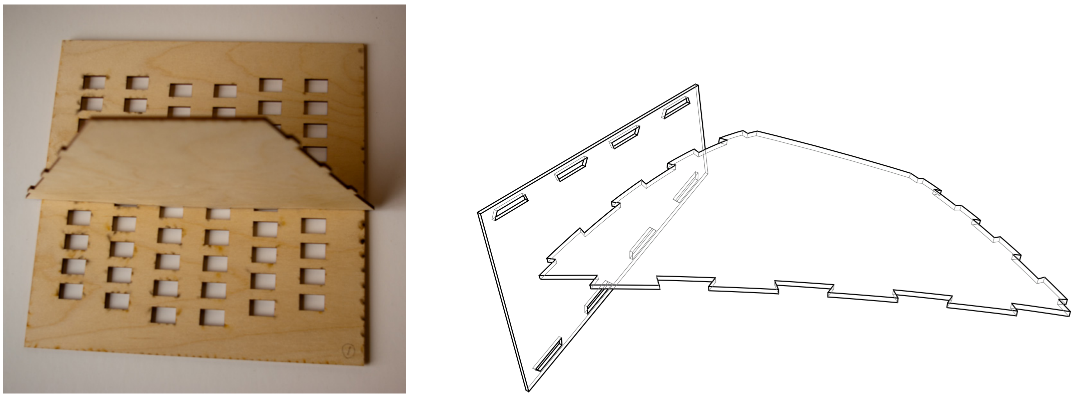


Fig 4.16 *Bending tests, to see how much the plywood could be bent by hand force in order to lodge itself in the connection holes.This information was then fed back into the parametric model. [Nordström and Orstadius, 2013]*

- Geometry of finger connections. These needed a lot of fine-tuning. They varied in length, so the width of the fingers needed to be sufficient for all lengths. It also turned out that although the structure would be almost entirely in compression, during assembly the hexagons would need some way of taking tension forces before the form was fully stable. The simplest way to acheive this was to make the fingers into little hooks, that could be wedged into the hole of the receiving plates.
- Minimum angle of meeting between the plates. When the angle was too acute, the holes holding the fingers would become too big, cutting outside the plate. This actually posed a restriction on the global form which was found interesting; the hexagons could not be too “squashed” lest the angles become too acute.

4.4.7 DESIGN TO PRODUCTION

In this design process, production was introduced as a factor from the start. The prospect of using CNC-milling machines informed the choice of working with 2D panels (along with the analysis benefits this would entail) and the need for hand assembly informed the detailing of the panels (in order for the hexagons to remain stable during the assembly).

In Grasshopper, the panels were modelled in the global structure and then marked with an individual ID number (systemized according to its place in the structure, Fig. 4.17) and oriented onto a flat surface, the measurements maximized according to the cutting machine.

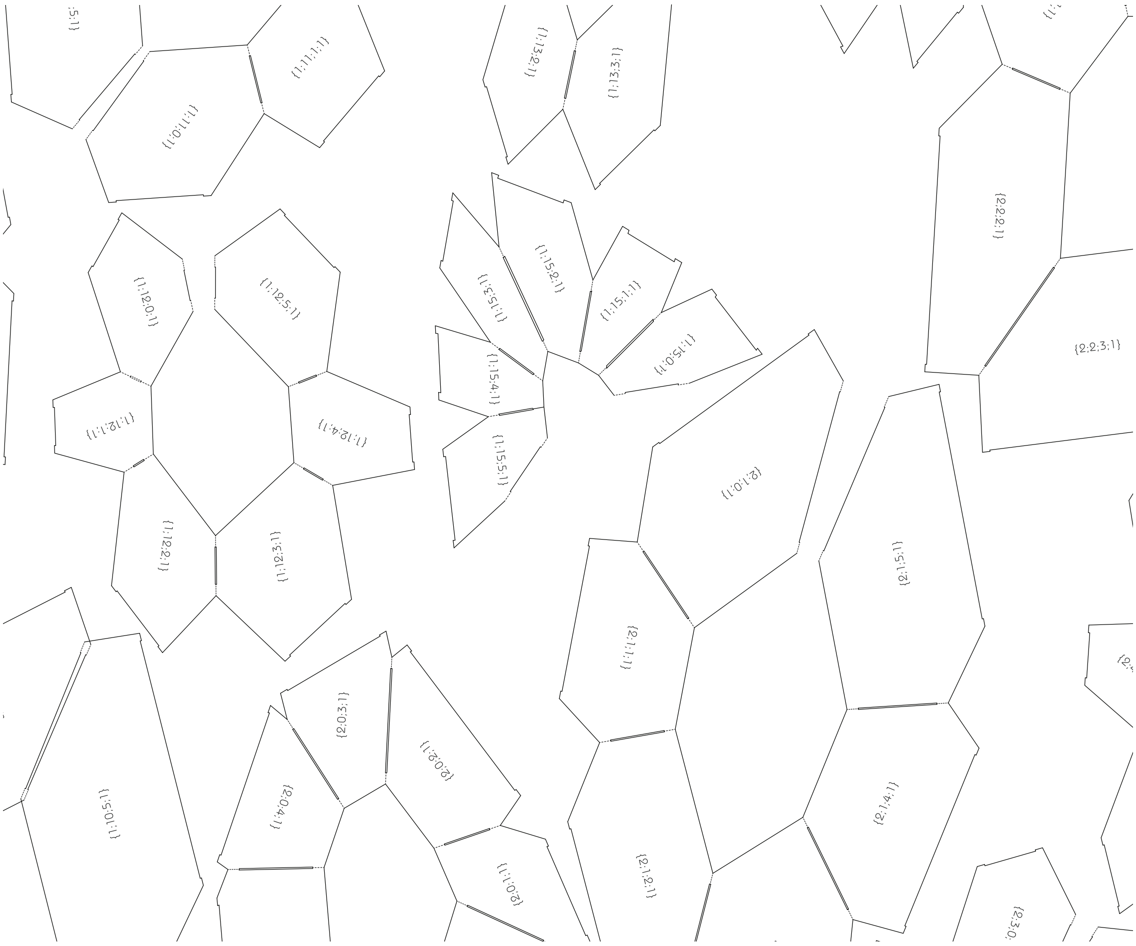


Fig 4.17 *Examples of the resulting dwg files with the drawings of the components and their ID numbers. [Nordström and Orstadius, 2013]*

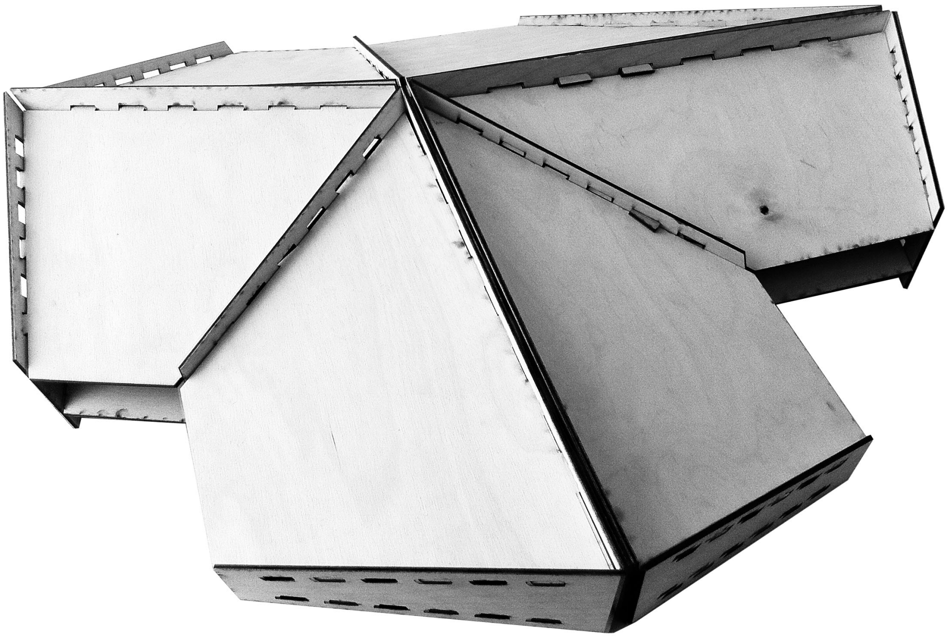


Fig 4.18 *A 1:1 model of the structure exhibited at Virserums Konsthall [Nordström and Orstadius, 2013].*

4.4.8 THE FINAL MODEL OF THE PAVILION

This was a very rapid design process, roughly three weeks from first sketch to developed structure. It is probably safe to say that this design could not have been realised without the aid of parametric design. The final pavilion consisted of over 700 individually shaped pieces, that were further modified by results from analysis, such as the removal of material where the stresses in the structure were predicted to be low.

A fullscale model of one of the connections was produced in 1:1 (Fig 4.18). It was lasercut out of 3 mm, 3-layer plywood. No tolerances were used, which posed a small problem during assembly, and would have had to be adjusted for a fullscale pavilion. It could however show that the connection design provided sufficient stability for both the construction phase and the life of the structure.

The final model of the full pavilion was built in 1:5 (Fig. 4.19). It was lasercut out of white 1 mm cardboard, each piece labeled individually with engraving to make assembly possible. Since it was lasercut the tolerances were neglectable, and no pieces had to be redone. In this small scale the finger connections were not included, but simply the shape of each piece, which was corrected in the parametrical model to accomodate the thickness of the cardboard.

Fig 4.19 *A 1:5 model of the structure exhibited at Virserums Konsthall, with the thesis authors [Nordström and Orstadius, 2013].*

5. CONCLUSIONS AND DISCUSSION

5.1 CONCLUSIONS AND DISCUSSION

This thesis has explored a parametric design process as an alternative for existing processes, comparing it to the design process of timber producer Martinsons. How can a design platform constructed with mathematical relations be beneficial compare to a regular CAD line drawing?

The tools explored in this thesis are still in their infancy, but they have unlimited potential. Grasshopper together with Rhinoceros works well as a parametric design and analysis platform due to its user friendly interface and its usefulness is continuously increased as new functions and plugins are developed. The evolutionary algorithm Galapagos is slow but relatively easy to use. Compared to FE-applications native to Grasshopper, such as Karamba, OASYS GSA has the disadvantage of requiring an external engine, but it is more advanced: it can understand anisotropy and handles complex geometries with ease.

A parametric platform is ideal for modeling complex geometry. The Oguni Dome features a local tessellation that would have been extremely time-consuming to model traditionally. In the parametrical systemization, the space frame structure could be mapped upon any surface, its measurements and density changed freely.

The link between Grasshopper, GSA and Galapagos was tested and found to work well. It was possible to model complex 3-dimensional shapes while still using a 2-dimensional analysis. The platform works very well for combining the strong modeling characteristics of Grasshopper and Rhinoceros with the optimization. The feedback was “instant” but a little slow. It was found that defining and restricting the system was especially important when running the optimization software, since the number of permutations grows quickly with increasing amount of data.

Analysis of complex beam structures in the parametric platform, in chapter 4.3, worked well. The different iterations were created rapidly and realistically and the geometrical representation could be used to clearly communicate the results. The drawbacks include mainly the speed, although it is much faster to model beam structures than is it to model a mesh. A general recommendation is to keep as much of the structural sketching to a conceptual beam model and only mesh what is really needed.

A potential way of saving processing power can thus be to choose typical details to analyze more thoroughly. If these are kept in the same model as the conceptual beam structure, the cut forces of the latter can influence them directly. This combines beam and mesh analysis and could be very efficient for testing connections. The next step would be for the mesh results to also affect the beam model, creating a sort of form-finding loop from detail to global scale and back again.

The improved connection between design and production was examplified in chapter 4.4, with a successfully modeled pavilion and produced physical demonstration models. Compared to a non-parametric design process, a lot of time was used in the early design stage, since everything had to be solved for the general case in order for the global variation to work. Once all the parametric relations were in place, the system had been "built" and a number of different structures were rapidly evaluated according to measured and subjective criteria, before settling on a certain iteration.

It was apparent throughout this design process that verifying digital models with physical ones was extremely important. Tolerances, material behaviour, geometrical aspects previously unthought of were all examined and solved with the aid of physical tests. Allowing the production conditions (such as the requirement for hand assembly) to affect the design process is essential. Therefore there is an interest in keeping the production tools as general as possible for the greatest flexibility in design.The importance of physical models to verify the parametric model cannot be overestimated.

Three design processes have been outlined in the thesis: the theoretical, as described by Engel; the pragmatic, as exemplified by Martinsons' and a work flow utilizing parametric design. Martinsons process is a linear one, placing large importance on the decisions made early on, since these cannot be changed easily. (Some parametric initiatives can be discerned, limited to a very narrow range of structures.) Evaluating many different structures early on in the design process using the categorisation made by Engel gives a possibility to choose a well suited structural concept and avoid late and costly changes.

The importance of systemization when working with complex structures is apparent when working with an open question of what structural system to use. In order to be creative and develop original structural systems a basic knowledge of existing systems is required. Engel outlines the importance of working from a system design level - bottom-up design - and not trying to fit a structural system within in a global shape outline.

New digital production tools makes complex structural systems easier to produce. It is necessary to be aware of the tools and work from their conditions from an early stage of the design process. Tailoring all components to their specific place in the structure, which becomes possible with a digitally automated production, can optimise performance and material efficiency. Working with complex structures it is important to use an unbroken chain from 3D design files of production, since every manual change and software conversion wastes valuable resources. The use of a parametric design process can fulfill this need of a unbroken chain. It uses one common platform for both geometrical generation, structural analysis and production information and therefore reduces the need of importing and exporting between programs.

A parametric workflow makes it makes possible to evaluate unlimited variations of the same system and produces precisely calculated outputs. A parametric model can be used as a communicative sketch tool and for multiple objective analysis, directly influencing the design with results from production limitation (see Fig. 5.1). A relatively large investment of time is needed for the set up of the first model, but when that has been finalized, the geometry can be changed and developed very rapidly. The tessellations of the structural system are produced instantly and interdependently.

One other drawback of parametric design is the required processor power. Since parametric models are recomputed with each change in the in data, they can be heavy to compute. This type of system design also requires a knowledge of programming which can be uncommon among structural engineers. If the platform is connected with several analysis programs the person defining the system needs insight into these as well.

Designing complex structures requires advanced knowledge of both geometry and analysis. Digital production tools have reintroduced a generality in possible results that is matched by that of advancing design programs and analysis tools. This generality and the possibilities it creates poses demands on designers and engineers of the future to be able to handle a vast array of options. A parametric environment is necessary for handling these options. Ideally, only the designer's imagination becomes the limiting factor.

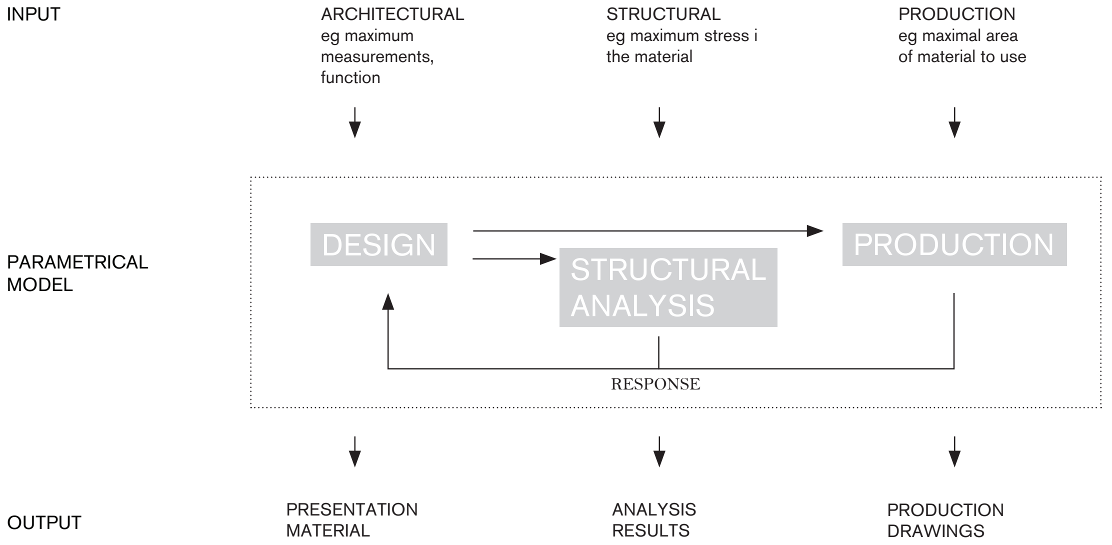


Fig 5.1 *The proposed work flow: A single model built from mathematical relations, which contributes to all stages of the design and production process. [Nordström and Orstadius, 2013]*

5.2 FUTURE WORK

This thesis is intended as a broad introduction to the work with parametric design. It opens up a number of interesting topics which need research:

- Further combining different design criteria in the same model: evaluate light and energy efficiency in the same model.
- More extensively comparing and validating different structural analysis softwares (Karamba, GSA etc).
- Building an open-source library of structural systems.
- Explore how contemporary engineers can start using these software and methods (already widespread among architects) and how the current design process in consulting can be adjusted to fit it in.
- Combining local and global structural analysis in one model (Fig 5.2).
- Final development of the 1:1 pavilion for Trä och Teknik-mässan in 2014.

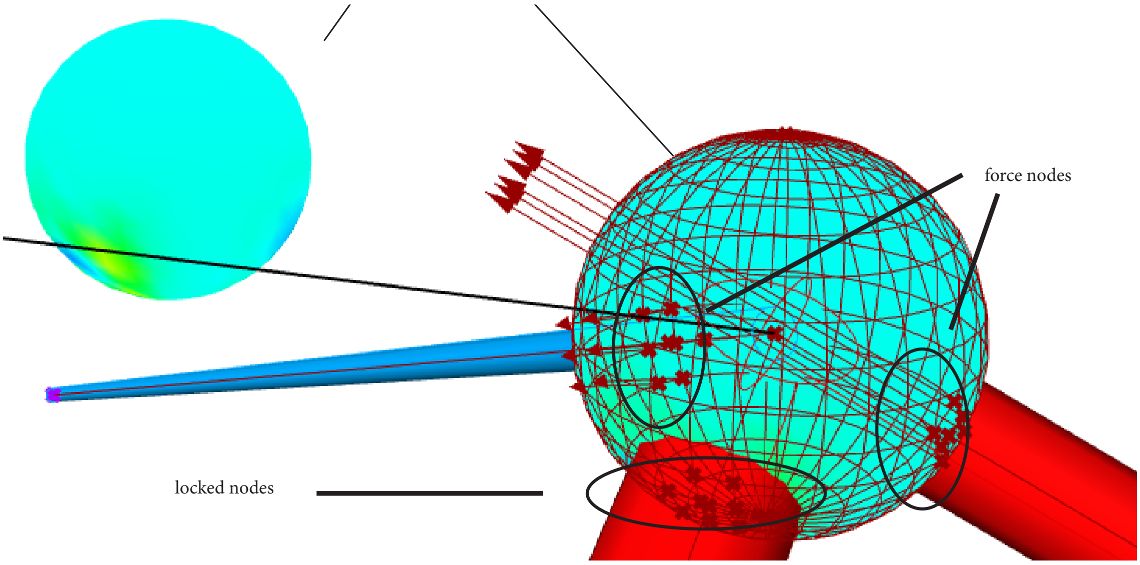


Fig 5.2 *One future development is to combine local and global analysis in one model, exploring for example how varying section forces change the geometry of connections. [Nordström and Orstadius, 2013]*

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APPENDICES

APPENDIX A

REFERENCE STRUCTURES: COMPLEX STRUCTURES IN TIMBER

Oguni Dome, vector active, Kumamoto, Japan.
This structure (Fig. A.1) utilizes a space truss system with Mero connections. Wooden bars are connected to steel spheres, 8 bars to each sphere. The system is statically determined and the bars are loaded with axial force. The slightly curved cupola shape of the roof decreases bending action in the global shape and helps decrease the structural depth of each member.

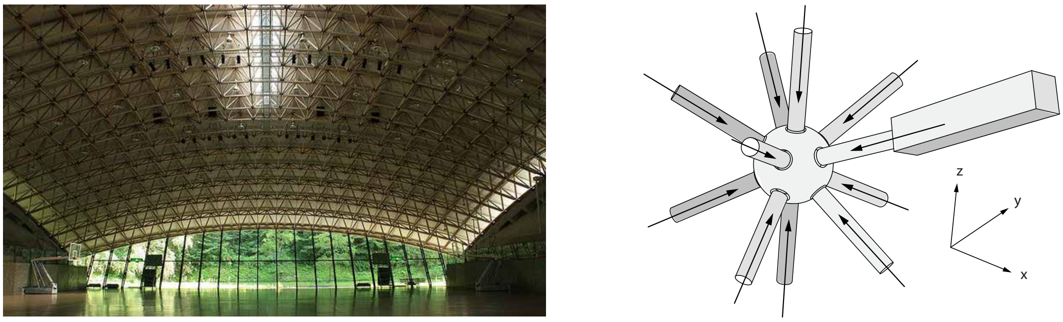


Fig A.1 *Oguni dome. Mero connection, with referenced axii. [http://goodfellamedia.com/2009/08/oguni-dome-kumamoto-japan-art.html]*

Serpentine pavilion 2005, section active, Alvaro Siza & Cecil Balmond, London, UK
This structure employs a Zollinger system, where equal size beams are criss-crossed into a pattern, see Fig A.2. The global force pattern is handled by bending, with the addition of compression forces from the rounded shape. The dense pattern prevents buckling and thus enables the use of much more slender beams (that can be milled out two-dimensionally). The connections transferes moment in one direction only.

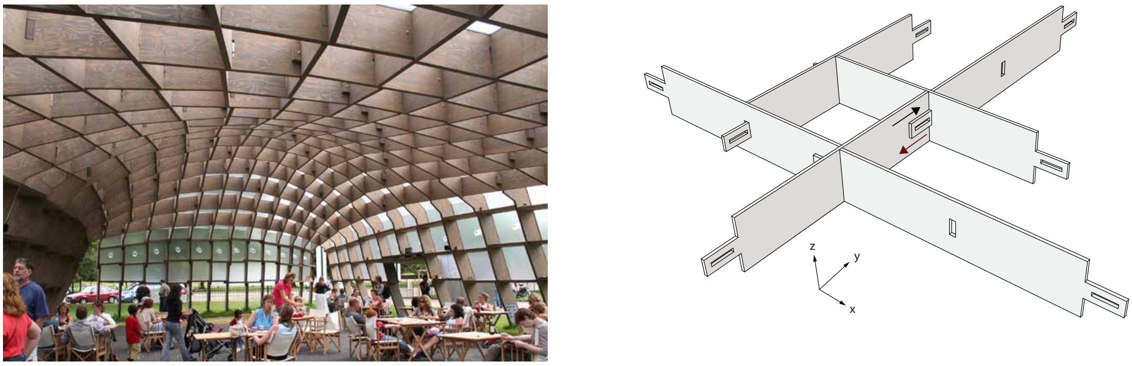


Fig A.2 *Serpentine pavilion and connection, with referenced axii. [http://viewoncanadianart.com/2008/07/21/news-frank-gehrys-serpentine-pavilion/]*

Saldome, Form active, Häring Engineers, Switzerland.
This structures is one of the world's largest timber domes, see Fig. A.3. Members work mostly in compression, with a thickness to handle secondary loads, primarily wind. The steel connectors join together six beams, creating a geometrically stable pattern and can only handle moments perpendicular to the primary load direction.

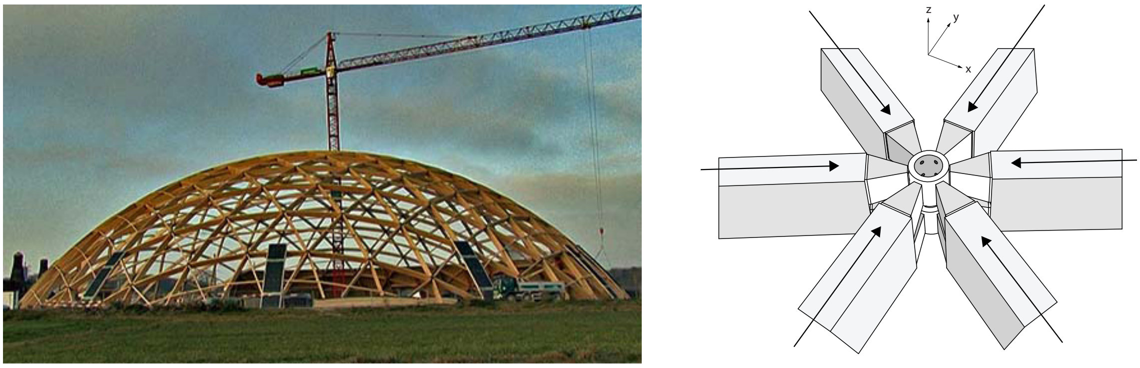


Fig A.3 *Saldome global form and connection with references axii. [http://ksuter.wordpress.com/2011/11/]*

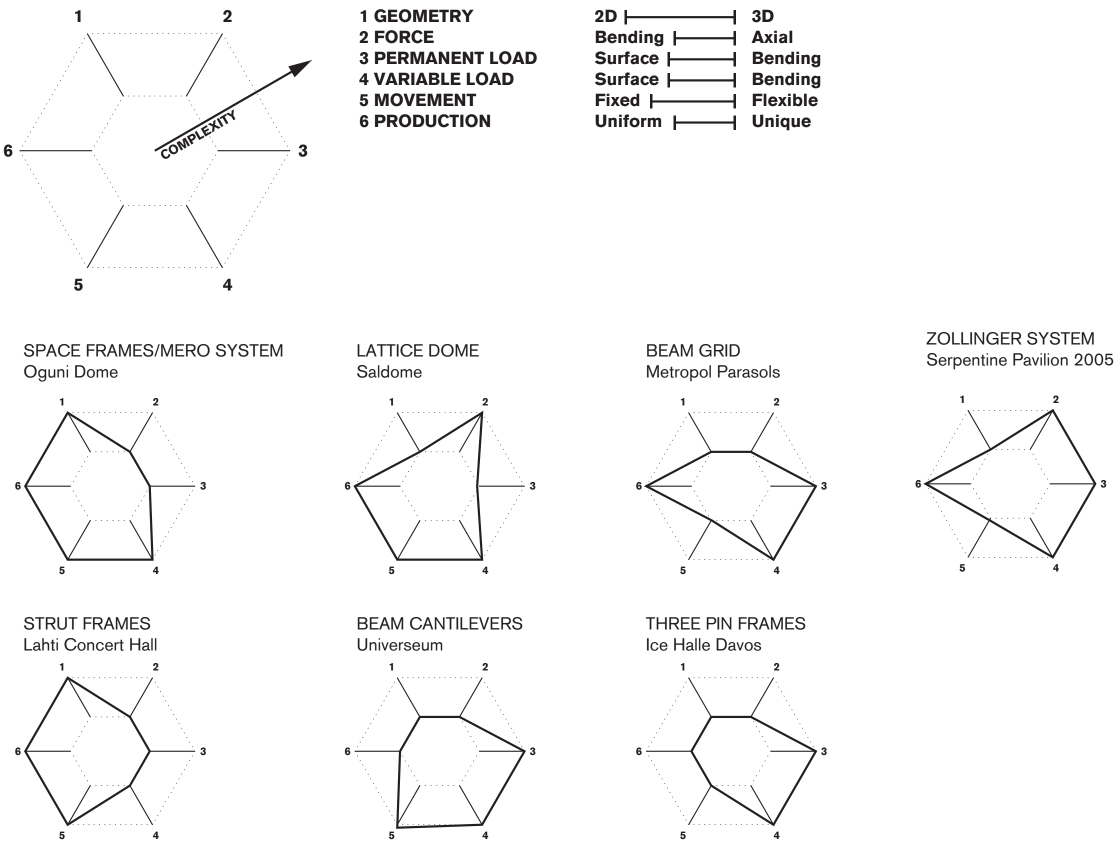
These three examples have been chosen because they fall into different categories of Engel's:

Saldome - form active
Serpentine - section active
Oguni dome - vector active.

By understanding these forms and confronting them with each other, some conclusions can be made about how structural systems are organized. In the interest of understanding how they have been built up, the individual parts in the systems are studied: the elements and the connections. How do these differ between the categories? Do different production conditions lead to different systems?

In the Serpentine pavilion from 2005, the connections are extremely simple and only transfers normal force allowing all the bending to be transfered by the elements. This is a fairly flexible system, since it works in bending it could have any form. The cupola form allows to work more in axial directions and thus have a smaller structural depth.

In a Mero system, only normal forces affect the connections. The system is geometrically stable, so the connections do not have to transfer any bending. In Saldome, the connections have the same thickness as the rest of the structure. They transfer moments due to secondary loads, but the system is stable in plane so the connections do not have to transfer moments there. The restricted form - working only in compression - pays off in the form of a small structural depth.



1 GEOMETRY	**2D**	**3D**
2 FORCE	**Bending**	**Axial**
3 PERMANENT LOAD	**Surface**	**Bending**
4 VARIABLE LOAD	**Surface**	**Bending**
5 MOVEMENT	**Fixed**	**Flexible**
6 PRODUCTION	**Uniform**	**Unique**

SPACE FRAMES/MERO SYSTEM
Oguni Dome

LATTICE DOME
Saldome

BEAM GRID
Metropol Parasols

ZOLLINGER SYSTEM
Serpentine Pavilion 2005

STRUT FRAMES
Lahti Concert Hall

BEAM CANTILEVERS
Universeum

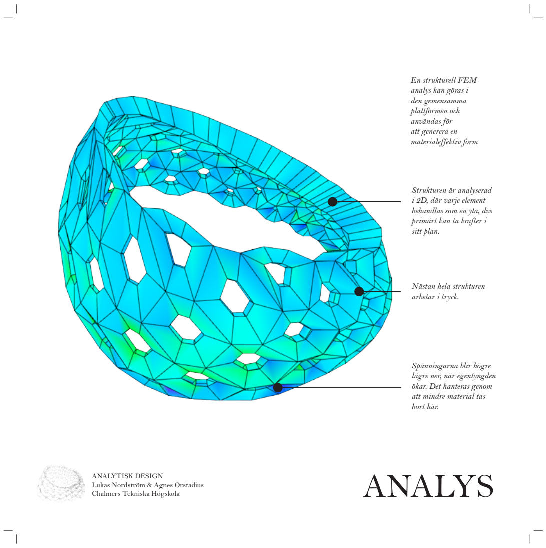
THREE PIN FRAMES
Ice Halle Davos

Categorization of different reference systems in an attempt to understand the relationships between different structural "families". Each reference is a fairly typical exmaple of its structural system.

APPENDIX B

VIRSERUM EXHIBIT: A PHYSICAL EXAMPLE OF THE PROPOSED PARAMETRIC PROCESS

A 1:5 model of the pavilion and a 1:1 detail model were exhibited at Smålands Trädagar, in Virserum, Sweden from June until December, 2013.



En strukturell FEM-analys kan göras i den gemensamma plattformen och användas för att generera en materialeffektiv form

Strukturen är analyserad i 2D, där varje element behandlas som en yta, dvs primärt kan ta krafter i sitt plan.

Nästan hela strukturen arbetar i tryck.

Spänningarna blir högre lägre ner, när egentyngden ökar. Det hanteras genom att mindre material tas bort här.

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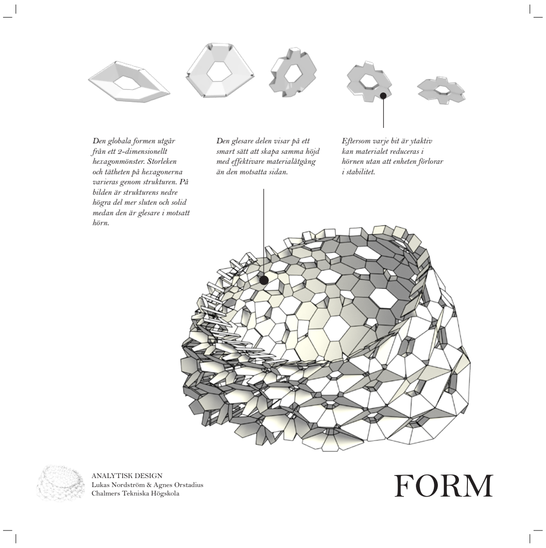
Lukas Nordström & Agnes Orstadius
Chalmers Tekniska Högskola

ANALYS



Den globala formen utgår från ett 2-dimensionellt hexagonmönster. Storleken och tätheten på hexagonerna varieras genom strukturen. På bilden är strukturens nedre högra del mer sluten och solid medan den är glesare i motsatt hörn.

Den glesare delen visar på ett smart sätt att skapa samma höjd med effektivare materialåtgång än den motsatta sidan.

Eftersom varje bit är ytaktiv kan materialet reduceras i hörnen utan att enheten förlorar i stabilitet.

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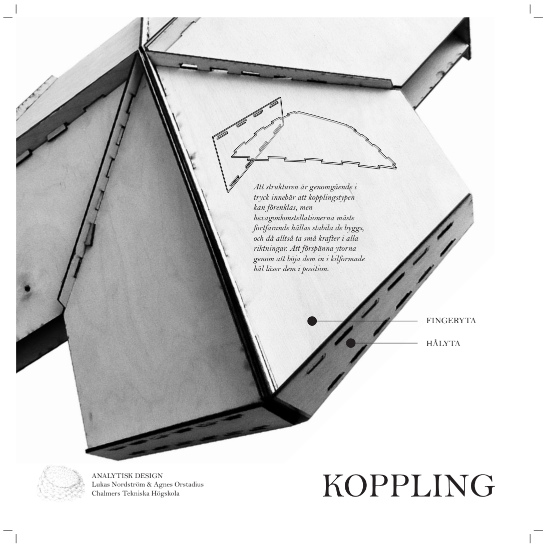
FORM



Att strukturen är genomgående i tryck innebär att kopplingstypen kan förenklas, men hexagonkonstellationerna måste fortfarande hållas stabila de byggs, och då alltså ta små krafter i alla riktningar. Att förspänna ytorna genom att böja dem in i kilformade hål låser dem i position.

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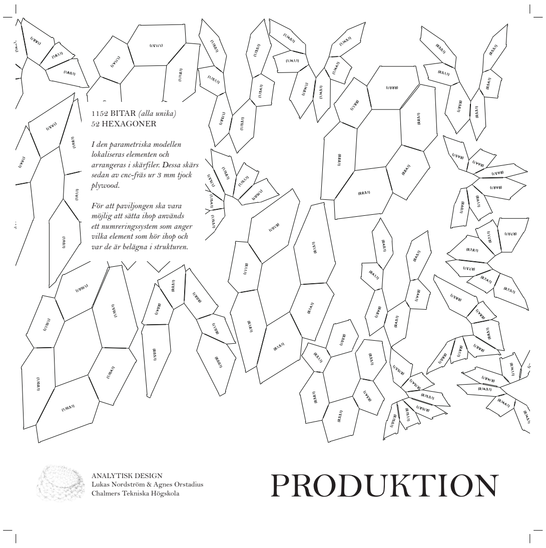
KOPPLING



1152 BITAR *(alla unika)*
52 HEXAGONER

I den parametriska modellen lokaliseras elementen och arrangeras i skärfiler. Dessa skärs sedan av cnc-fräs ur 3 mm tjock plywood.

För att paviljongen ska vara möjlig att sätta ihop används ett numreringssystem som anger vilka element som hör ihop och var de är belägna i strukturen.

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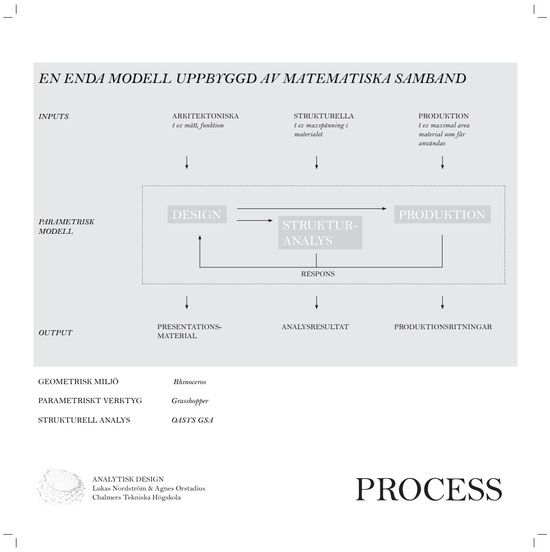
PRODUKTION


DETALJMODELL 1:1

Att strukturen är genomgående i tryck innebär att kopplingstypen kan förenklas, men hexagonkonstellationerna måste fortfarande hållas stabila då de byggs, med små krafter i alla riktningar. Att förspänna ytorna genom att böja dem in i kilformade hål låser dem i position.


EN ENDA MODELL UPPBYGGD AV MATEMATISKA SAMBAND

INPUTS

ARKITEKTONISKA
t ex mått, funktion

STRUKTURELLA
t ex maxspänning i materialet

PRODUKTION
t ex maximal area material som får användas

PARAMETRISK MODELL

OUTPUT

PRESENTATIONS-MATERIAL

ANALYSRESULTAT

PRODUKTIONSRITNINGAR

GEOMETRISK MILJÖ *Rhinoceros*
PARAMETRISKT VERKTYG *Grasshopper*
STRUKTURELL ANALYS *OASYS GSA*

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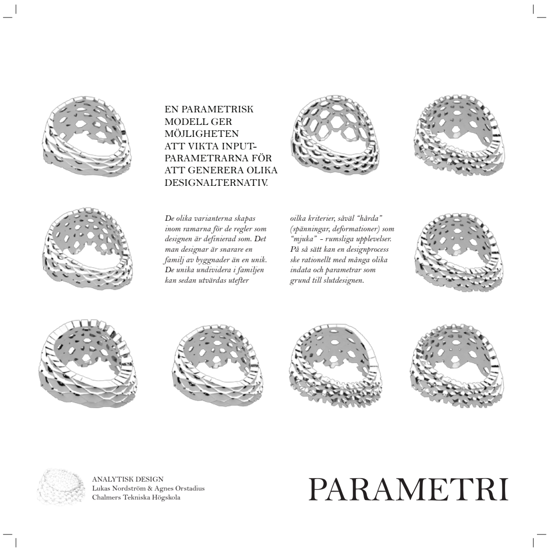
Chalmers Tekniska Högskola

PROCESS


EN PARAMETRISK MODELL GER MÖJLIGHETEN ATT VIKTA INPUT-PARAMETRARNA FÖR ATT GENERERA OLIKA DESIGNALTERNATIV.

De olika varianterna skapas inom ramarna för de regler som designen är definierad som. Det man designar är snarare en familj av byggnader än en unik. De unika undividera i familjen kan sedan utvärdas utefter oilka kriterier, såväl "hårda" (spänningar, deformationer) som "mjuka" - rumsliga upplevelser. På så sätt kan en designprocess ske rationellt med många olika indata och parametrar som grund till slutdesignen.

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PARAMETRI


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Vi är masterstudenter på Arkitektur och teknik på Chalmers, och sedan i januari har vi arbetat med vårt examensarbete inom Structural Engineering. Efter studieresor i Sverige och till Schweiz och Österrike har vi samlat en bild om vad vi tror är framtiden för skapandet av innovativa trästrukturer: en samlad process där arkitektur, konstruktion och produktionsförutsättningar påverkar varandra redan från början.

I projektet har vi utforskat möjligheter med nya digitala verktyg för trästrukturers designprocess. Vi har undersökt en parametrisk plattform där vi kombinerar design, strukturanalys och produktion. Det parametriska förhållningssättet ger oss möjlighet att definiera en geometri utifrån regler och matematiska samband, där vi använder våra arkitektoniska förutsättningar som indata. Därefter kan vi enkelt ändra modellen enligt reglerna och optimera den enligt våra villkor.

Modellen du ser är ett exempel på den typ av process vi tänker oss. Paviljongen är parametriskt modellerad, och samtidigt strukturellt analyserad för att se till att dess globala form är stabil och att spänningarna som uppstår inte överstiger materialets hållfasthet. Formen påverkas alltså direkt av resultatet från analysen. Bitarna arrangeras sedan för att skäras ut av en cnc-fräs, där skärtiden är samma oavsett variationen på elementen. Paviljongens delar varieras i all oändlighet och storleken och formen anpassas helt fritt.

Paviljongen kommer att byggas i fullskala i Virserum under september 2013.

Projektet genomförs i samarbete med Martinsons.

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POSTERS - LÖSA TANKAR

format: 297 x 297
kanske 4 st?

saker vi vill berätta:

intro: vilka är vi, exjobbet, vad vill vi visa med paviljongen, parametrisk design.
Möjligheter när man arbetar integrert med kontroktion och arkitektur design och produktion, parametrisk design på en gansk almän nivå

stats: (kanske bild på skärfilerna?)
1240 bitar (alla unika), 45 hexagoner, vikt, ytareal, skärlinje, skärtid... sifferlista! (mums)

parametrisk global geometri: (ex make2dbild)
- alla bitar är unika
- storleken på hexagonerna följer den globala formen
- alla bitar fyrkantiga: för att undvika dubbelkrökta ytor riktar de sig mot en mittpunkt

kopplingar: (detaljbild)
- hälften av bitarna har tänder och hälften har hål. de som har tänder fäster i dem som har hål och stabiliseras av dessa.
- varje ytbit bär i sitt plan, vilket innebär att kopplingarna främst är utformade för att ta skjuvning

hållfasthet: (FE-bild)
- analyserad i 2d, som ytor
- varje hexagon är en stabil form i sig själv
- hela strukturen i tryck: ...möjliggör en enda kopplingstyp
- högre spänningar lägre ner där egentyngden ökar: mer material

process: (kanske bild på grasshopperkod?)
- OASYS GSA
-

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FAKTA