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COMPUTATIONAL DESIGN DEVELOPMENT OF A WOODEN FAÇADE SYSTEM

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ABSTRACT: The implementation of computer design within the building industry has created new possibilities for creating digital tools for users such as architects. There is however a lack of easy to use, efficient digital tools to aid and explore design alternatives for architects when using products within the wood building industry. This paper demonstrates how a modular facade system in wood can be adapted for facade configurations in different contexts by using computational design.

The goal is to develop a digital design tool that is easy to use and provides the architect with a high degree of freedom to create project-unique facades. The design tool is developed with computational design methods for flexible and adaptive design. In parallel, assessment is made that the design solutions can be manufactured smoothly and quickly via digitalization and industrial production. The result of this research shows that the façade system can be customized by using parametric programming methods, and thus enable architects to design facades for different contexts. The design tool was verified with the architect partners concerning usability and manufacturers concerning production.

KEYWORDS: Façade design, Cladding, Heartwood, Parametric design, Adaptable design, Digital design tool

1 INTRODUCTION

Advances in computational design introduces new possibilities for designers, architects, and the wood building industry to collaborate from the initial idea thru the development process to a product ready to manufacture [1,2,3,4]. Previous research has shown that computational design approaches can be used to support the exploration and optimization of design solutions in the building design process [5]. In this paper computational design means a design method using algorithms and parameters to solve design problems by computer processing. Computational design methods support "file-to-factory" processes and interdisciplinary collaborations; it also enables adaptive design towards different contexts and cost-effective manufacturing.

The implementation of computational design within the building industry has its challenges. There is a need to clarify how and when different computational design approaches can be used to support the building design process [5].

There is a lack of easy to use, efficient digital tools to aid and explore design alternatives for architects using products within the wood building industry.

Since the Swedish wood industry is highly digitalized, it can serve as a good foundation for advances in computational design methods.

Parametric design, a software-based programming method, has proven to enable a creative exploration in design development. Data input can be gathered and organized rendering it usable in automated generation of design alternatives. This can be done manually by a user or for instance, using an automated algorithm [6].

Adaptable design is a design paradigm aiming at creating designs and products that can be adapted for different requirements and be influenced by users. An existing design of a product can be adapted to create a new or modified design based on changed requirements. Adaptive design enables manufactures to produce standardized products that are possible for end users to customize [7].

The goal with this project was to develop a digital design tool easy to use for architects when designing an adaptive wood façade system.

This paper demonstrates the use of computational design methods for developing a design tool to enable the façade system to different configurations. Thereby aiding architects in design decisions combined with a freedom to create project-unique facades and manufacturers by

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assessing that the generated digital data is prepared for use in production so called “file to factory”.

A group of residential buildings in Lombolo, Kiruna Sweden, owned by Kiruna Bostäder AB are used as case to test the digital design tool. Figure 1 shows one of the façades in Lombolo.

***Figure 1**: One of the façades today in Lombolo, Kiruna, Sweden. Photo by Karin Sandberg.*

Two case studies using definitions of case study approaches by Yin [8] are presented.

The façade system discussed in this paper was developed in the project “The facade of the city Swift, Stylish, Smart” [9,10] hereafter called the façade project. It consists of an industrial prefabrication of façade elements, corners and connections to windows and doors.

2 MATERIAL AND METHODS

For development of the design tool and the digital workflow a computational design approach was used, which requires information to be digitalized and organized so that it can be used in the automated generation of design alternatives.

The included parameters in the two studies were based on data collected from the façade project [9]. To test the digital design tool, data from the case in Lombolo was used.

The data collected from the façade project consisted of digital models of the façade element and corners. Data collected from the case was boundary information acquired from the configuration of one of the façades by drawings and site visit. Figure. 2 shows examples of collected data.

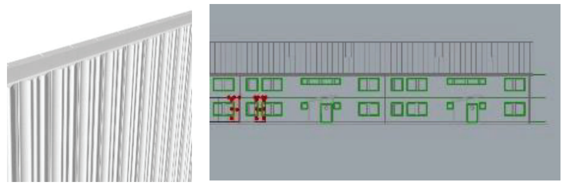

***Figure. 2:** To the left - detail of the façade element model, to the right -boundary data from the façade case in Lombolo. Image by Camilla Schlyter.*

The facade system in this case is a facade solution for buildings consisting of a set of components assembled to elements that are fully or partially ready-made and dimensioned regarding adjustment for specific dimensions of buildings, and industrially manufactured. The components of the facade system are joined industrially to facade elements.

The facade system consists of a combination of adaptable elements. The element dimensions are possible to customize for users, such as height, width and surface design but the interfaces between components and assembly components are not possible to customize for users.

2.1 IMPLEMENTATION OF THE TWO STUDIES

2.1.1 Case Study 1

Research question for case study 1: How can an adaptable façade system be explored and optimized using a computational design approach?

The case study was conducted using an explorative approach as described by Yin [8]. The purpose with case study 1 is an exploration of possibilities and functions concerning a digital design tool for enabling design of a and adaptable façade system. Requirements on the digital design tool are: that is easy to use and provides the architect with a high degree of freedom to create project-unique facades within the products design possibilities and limitations. The design tool was developed with computational design methods for ensuring flexible and adaptive design for the user.

In case study 1 a digital design tool was developed to enable the façade system to be easy for the architect to use for different façade configurations. The design tool was developed using parametric design methods. This was done by developing the product´s design rules in parallel with manufacturing processes to assess that the generated data could be used with industrial production techniques. For manufacturers, this means that the façade system can be reused for the development of new designs to save product development time and costs. For architects this means that an adaptable design product gives them the opportunity to design in different ways for different contexts, having the security of using a predefined façade system.

The design tool's function and usability were verified in parallel in workshops together with a reference group of three architects, having different levels of knowledge of computational design from proficient to general user.

2.1.2 Case Study 2

Research question for case study 2: How can a computational design approach be integrated in a digitalized workflow in the value chain of an adaptable façade system?

The case study was conducted using an explorative approach as described by Yin [8]. Case study 2 concerned how the digital information created in case study 1 could travel thru a digital value chain, from design to manufacturing. Ensuring that the design solutions made by the architect can be manufactured smoothly and quickly by industrial production within the boundaries of the façade element design. A prototype of a future digital workflow was developed estimating the required information in the different stages in the design- and manufacturing process. The purpose was gathering knowledge of the requirements of data in the different stages in the value chain so that, in the next step enable a seamless digital workflow without digital information and design intent getting lost thru the value chain.

Moving into fabrication it is important to analyse how to use the "cocktail of software" available. The analysis was managed by using design methods to eliminate data and assess what data is necessary at different points through the whole value chain.

To solve this analysis of available software that allows for information exchange between different systems and tools is required.

For the control files used in industry, transfer of the information is needed from the software architects commonly use such as Autodesk Revit (Revit). In this study Microsoft Excel files (Excel) or Autodesk AutoCad (AutoCad) was used as a middleware between different software. From Excel, for instance, wood cutting lists can be made enabling feeding into the manufacturing machines.

3 RESULTS AND DISCUSSION

3.1 CASE STUDY 1, DEVELOPMENT OF THE DESIGN TOOL

The requirements of the design tool:

- Provide that the facade elements can adapt size wise to different façade contexts.
- Manage different measurements, such as variation of floor level hights and window openings.
- Adapt the size of the façade elements to production, transport and assembly.

Digital models of the facade system were built up using Rhinoceros 3D (Rhino) and Grasshopper software. Thereafter a prototype of the design tool was created using Rhino, Grasshopper, AutoCad and Revit. Revit is commonly used by architects and engineers in Sweden. Dynamo is an extension to Revit and Grasshopper is an extension to Rhino and both Dynamo and Grasshopper enable parametrization. Parametric software such as Rhino thru its extension Grasshopper is seldom used in the wood construction industry, but is interesting since int can provide important digital data concerning customization in the value chain.

What sets computational design approaches apart from more conventional design methods (where the user usually reacts with digital sketches, drawings, or models) is that the user instead interacts with the digital environment and the mechanisms responsible for generating digital representations [10]. The architect can see and interact with the design in real time, adjustments made are visualized immediately.

Using parametric design enabled exploring the structure of relationships between the parameters in the façade system. By using parametric design, it was possible to use algorithms to design boundaries for both, the predefined, standard components (not customizable for users) and the adaptable components (customizable for users).

Case study 1 consisted of four phases:

3.1.1 Phase 1: Inventory of design criteria and design tool

The objective:

- Initial discussion on suitable programming for the design tool prototype.
- Analyse the design criteria, established in previous research, by studying the variability of the components to assess what parts required adaptability towards different contexts and which could remain static.
- Model façade elements and components in Rhino.

Components in the facade system that should be customizable for the user were already established in the previous façade project. After discussions in the project- and reference group it was concluded that the size and adjustment to openings of the facade elements was interesting to explore. The decision was also based on inventory and experience of the façade projects manufacturing processes and aesthetic analyses.

The decision established the boundaries of the case study. Initial analysis of different software was conducted thru a series of meetings within the research group where

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possible capacities for automating design procedures, i.e., what the software needed to achieve was discussed. This concerned searching for a method ensuring that the facade elements could be adapted size wise to different façade contexts, including different measurements, floor level heights, and window openings. The initial discussion on suitable programming for the design tool prototype was important, since it created a background for important knowledge for the data collection in the next step. Figure 3 shows ideas for different configurations for the façade elements from the façade project.

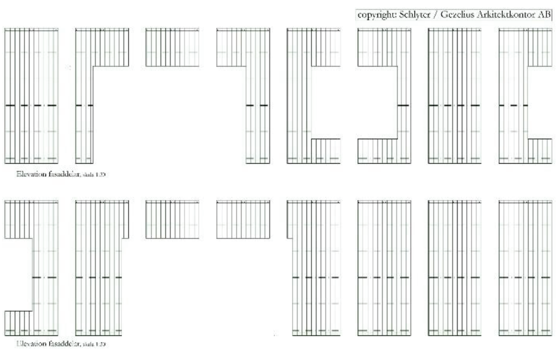

Figure.3: *Exploring the size of the façade elements, from the earlier façade project. Image by Camilla Schlyter.*

The analysis concluded that parametric design was suitable for the façade systems properties, combined with the potential of reducing the amount of time and effort needed to obtain optimized façade solutions for every situation. The hypothesis was that parametrization would enable that the façade system, in a new context, could be created without the need for redesign of the whole system. The façade elements and components were modelled in Rhino to aid in assessing variability, by visualisation. Figure 4 shows evaluation of façade element components that must be considered, such as height, width, thickness, distance to attachment etc.

Figure 4, *Phase 1 resulted in an analyse and overview of the design variability of the components from the project. Image by Camilla Schlyter.*

3.1.2 Phase 2: Systematizing input data

- The objective:
- Study of the components in the facade element in more detail.
- Develop data concerning which components could stay "standard" and which should be able to customize.
- Systemize the input data.

Systematizing the required data resulted in a structured and detailed excel file for identifying data input for digital parameterization. The Excel file was constructed specifically for data input for use in digital parametrisation and aided in establishing a suitable hierarchy, going from system components to data needed for adaptation of the façade elements to the specific case, the building in Lombolo. Summarizing the hierarchy in the Excel file see figure 5.

System level, concerns variables of the components
- Boards, joints, surface, etc.

Existing building
- Façade, plan, width, height, windows etc.
- Floor levels, height etc.

Adaptation of façade element to existing building
- Module, façade system, width, height, littera etc.

Figure 5: *Hierarchy for data input for digital parametrization concerning variables in case, Lombolo. A short summery of the Excel file where information was collected concerning data for digital parameterization.*

The result from managing the large excel file added to the understanding of required additional data input, but also of exactly which data that was essential at a specific level. The data input was discussed with the manufacturer to assess that all required data was accounted for. The Excel file was continually reworked as the study developed.

3.1.3 Phase 3: Test of software

The objective:

- Evaluate programming solutions and software, to ensure that possibilities were not overlooked.
- In Revit the min-max possibilities of the facade element and ways to subdivide the model was tested.

In phase 3 different software and programming solutions to enable the façade system towards different configurations were tested using an iterative approach.

The result from phase 2 was used as background data. Revit, Dynamo, Rhino, Grasshopper and AutoCad software were tested and analyzed see figure 6.

- Revit, with BIM modelling capabilities, is good on documentation and tracking capacities, but lacks parametric features and generation of complex geometry is limited. The Revit structure with families can be a good way of organizing the data in later development when creating an end user interface.
- Dynamo, interesting for next stage in the development in combination with Revit.
- Rhino, lacks BIM modelling capabilities but enables optimization exploration thus making it an ideal platform for design analysis.
- Grasshopper, is an extension of Rhino and has good parametric capacities. Grasshopper enabled the possibility to parametrise the facade system according to the excel sheet and enabled adjustment of the facade system to the case.
- Autocad, contained the component details of the fasade system and was used as a base for modelling in Rhino.

Figure 6: *Test of software with short comments*

Phase 3 resulted in choice of software. The design space of Grasshopper/Rhino proved easy to work with and test solutions valid for the study. Grasshopper/Rhino enabled the possibility to parametrise the facade system according to the excel sheet and adjust the facade system to the case.

3.1.4 Phase 4: Adaptable design

The objective:

- Programming in Grasshopper enabled testing a prototype solution of the design tool. A code for automatic subdivision of facade elements was sketched in Grasshopper, including a "sanity" check.
- Verification of the design tool with a reference group of users, architects.

Phase 4 resulted in a prototype design tool, for adapting the façade elements to different façade configurations using parametrization software. Assessment was made that the façade element details, design criteria, material characteristics, dimensions, material properties can be formulated in program code to provide customized design output, see figure 7, 8.

Figure 7: *Screen shot from Grasshopper, showing boundary lines and a script running on an underlay of a drawing of the residential block in Lombolo. Image by Ola Jaensson and Camilla Schlyter.*

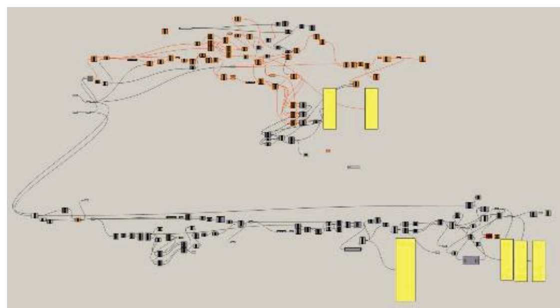

Figure 8: *Screen shot from Grasshopper showing the script. Image by Ola Jaensson and Camilla Schlyter.*

Verification of the design tool with the reference group of architects was done at two occasions. The first meeting was a teams meeting, securing that the chosen variables were valid, in this meeting the manufacturer also attended ensuring that manufacturing data was provided. The second meeting at Equator architects concerned testing the usability of the prototype design tool together with three architects. The architects tested the prototype design tool on the case façade using drawings of a residential building in Lombolo, first applying boundary lines and thereafter creating a façade layout. The result of the test showed that it enabled the architects to create a façade layout quickly once they had set up the boundary lines of the façade. The immediate response was positive and the design of the façade system was much appreciated. The result of the meetings were documented in meeting protocols.

3.1.5 Comments on the results

A master model concept, such as Revit can be used in the future to structure and contain the components and their link inputs, outputs, and processes. BIM software such as Revit can be used as a container to define the façade system, its design variables, constraints, and objectives, and thus support manufacturing.

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The software combination of Grasshopper/Rhino worked well in study 1. Revit is suitable for documentation and tracking key information but is not suitable for generating complex geometry nor for analysing real-time simulations, both possible in parametric software. Based on study 1 conclusion was made that further explorations of the "cocktail of software" i.e. middleware is an interesting way to continue the research.

To facilitate information exchange and interoperability for the systems involved in computational design approaches, middleware components can be used as an interface to support information exchange. This could facilitate the integration of existing computer-based methods and tools in BIM-based workflows into computational design approaches.

Important knowledge was gathered concerning how to adjust the programming and data input for the next step. For example, concerning rules on how to cut the individual façade elements when manufacturing the façade system. Figure 9 shows a diagram summarizing the development process of the design tool.

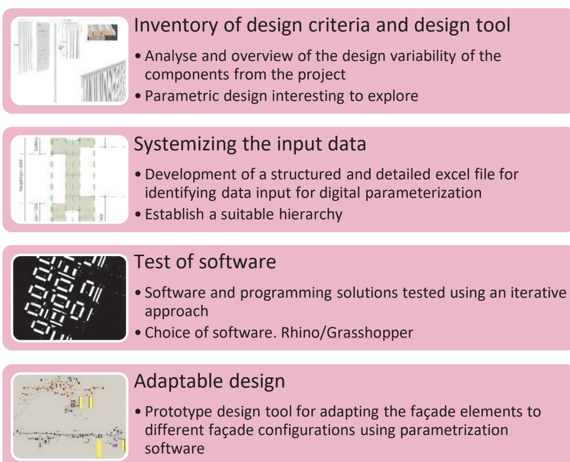

Figure 9: *The digital design tool process*

3.2 CASE STUDY 2, THE FUTURE WORKFLOW

Case study 2 concerns a prototype of a future digital workflow estimating the required information in the different stages in the value chain using the case of adjusting the façade system to a building in Lombolo.

3.2.1 Telling the digital tool what the project is, going from general to specific input

Since the digital tool accepts a generous variety of input, an automatic sanity check was programed enabling the result to be visually communicated to the user. This was done with the purpose of warning when the values or resulting calculated properties seem suboptimal or invalid.

3.2.2 The construction system

Example of system level parameters:

- Wood component dimensions
- Detail dimensions, distances, limits, shapes, and choices
- Standard module width
- Minimum and maximum module height

Proposed next step in the development of the tool: Surface ornamentation type.

3.2.3 The manufacturer

Here, and the properties of the manufacturer's tools, materials and processes are to be defined.

Examples of manufacturer parameters:

- Standard green wood dimensions
- Machines and tools used for a specific construction and design.
- Cost-driving parameters for different machines and treatment methods.
- Preferred output file formats for specific machines such as the g-code, a programming language for CNC (Computer Numerical Control) machines. G-code stands for "Geometric Code". A G-code tells a machine what to do or how to do something for instance, instruct the machine where to move, how fast to move and what path to follow and others etc.

3.2.4 The project parameters

In this level, the specific project is created and defined. Examples of project parameters:

- Project name
- Geographic location of project (project origin)
- Other administrative data
- Project units
- Number of buildings

3.2.5 The building

In this level specific project data is required. Examples of building parameters:

- Building names
- Ground contour polylines
- Number of facades
- Number of levels

3.2.6 The buildings façades

Examples of existing facade parameters:

- Elevation contour polylines
- Wall opening contour polylines.

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3.2.7 New façade parameters

Examples of new façade parameters:

- Elevation division levels (Z values, the bottom alignment lines of the façade modules)
- Number of modules
- Left and right corner/end module types
- Offset to first façade module.

3.2.8 Dance of adjustments

Dance of adjustments, test of different façade layouts until desired design is achieved. After the design tool has been fed with user input, the façade element generation algorithm calculates necessary directly related parameters and makes a first automatic element division elevation per façade and level.

Figure 10 shows a screenshot from a first automatic element division. This can be adjusted by the user if the division does not comply with the wanted design outcome, but always within the programed boundaries.

Figure 10: *A screenshot from Grasshopper showing a first automatic element division on a façade in Lombolo.*

3.2.9 Outputs

Examples of output and formats:

- Excel module property lists.
- Timber cutting lists.
- Waste prediction
- CO_2 and other resource calculations
- Lists of assembly jig support positions for each module or sub-component.
- Visualization oriented, detailed geometry.
- Metadata-rich BIM geometry.
- Overview elevation drawings with façade modules annotated.
- Annotated construction drawings of individual façade modules.
- Wood shop CNC machinery G-code

4 CONCLUSIONS

The design tool, the result of this research, shows that the façade system can be customized by using parametric programming methods, and enable architects to design facades for different contexts. This has been shown thru analysing the result of the design tool together with architect partners. Assessment has been made that the façade elements details, design criteria, material characteristics, dimensions, materials' properties can be formulated in program code to provide customized design output. Knowledge has been gathered on how to adjust the programming and data input for the next step, the development of a plug in for BIM software such as Revit.

Assessment has been made that the digital information gathered in case study 1 can be used for manufacturing. In case study 2 the digital flow has been hypothetically tested thru the value chain in close collaboration with industry partners. Though the results have to be further confirmed to assure that the façade system will be possible to manufacture smoothly and quickly, best assessed thru physical prototype tests with the industry partners.

An assumption made in the project is that Revit can be interesting for a commercial application in a future by developing an end user interface thru a customized plug in. A plug in is a software component that adds a specific feature to a software that enables customization. The plug in can be infused with diverse input data concerning material properties, keying the specific elements placement in a project and cost et cetera.

Future development can include how numerical data in middleware can be fed into Revit via parametric software to control the parameters of Revit Family components aiming towards a plug in a Revit environment. Thru the Revit family's output, for example, cutting files for the timber industry and control files for manufacturing can be created.

The project shows that the wood building industry can adapt computational design methods when developing adaptable building products. The methodology precented in the paper also provides a possible scaling-up effect applicable to other products. The next step is to further develop the design tool and test it on façade configurations of different design.

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