Enhancing the value of customization in the Swedish prefabricated housing industry

An architectural design approach
Acknowledgements

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Abstract

Houses are unique personal spaces and individuals want flexibility and personalization in building their dream house. There is a current challenge in the prefabricated housing industry in Sweden where customers have increasing design demands and options that in essence, defeat the purpose of fixed design and prefabrication. This causes strain to both the customer and the company’s design process and sustainability efforts.

**Purpose:** The purpose of the study is to map the customer demands in customization of prefabricated houses through the innovation process of ideation, realization, and implementation.

**Findings:** The overarching strain in customization is due to (1) the complexity of choice in designing a house, and (2) the mismatch between customer demand and manufacturing capability. A design criteria with BIM was brought forward to aid in the customization process in being more objective for decision-making. Through a case project and a design criteria, a prefabricated house model was redesigned with maximized flexibility.

**Practical Implications:** The findings in this study is a contribution to the house manufacturers in Sweden as an aid in architectural design and client communication strategies.

**Keywords**

Customization, prefabrication, modularity, BIM, sustainability
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1. Introduction

In this first chapter, the prefabricated single-house industry in Sweden is discussed. This is followed by describing the challenge of customization. After which, the chapter covers the project description, relevance of the study, purpose, scope and limitations, and the overall flow of the study through a report outline.

1.1 Background

The construction industry is a main consumer of natural resources and generates about 39% of the world’s greenhouse gas emissions (Rakhsha, Morel, Alaka & Charef, 2020). In Sweden, prefabricated single-houses are currently dominant with as much as 80% in market shares. The industry was established in the 1960’s and since then has been evolving to be sustainable and efficient (Jensen, P., Olofsson, T., Sandberg, M. & Malmgren, L., 2008). Being the dominant market participant, the strain in customization has become a challenge that affects the overall sustainability performance of the industry.

With the aim of efficiency and cost-effectivity, the construction of houses in Sweden has adopted prefabrication. This is the process of constructing house components in an off-site controlled environment and transporting it to the site of construction to be assembled. Studies and practice show that prefabricated design in houses achieves controlled energy use, minimizes waste, assesses energy efficiency, and allows for precise and calculated use of construction materials (Steinhardt, D. & Manley, K., 2016; Monahan & Powell, 2011; Pan & Goodier, 2011; Eastman and Sacks, 2008). It is a way to be efficient in the production process, to ensure quality and durability, and to evaluate environmental performance in house construction (Goodier & Gibb, 2007).

However, high standardization gives a rigid impression and does not satisfy the customer's need for personalization and customization. (Nadim & Goulding, 2011; Anebyhusgruppen 2022). To address this, companies in the business of prefabricated houses sell a wide range of model houses and give the customers the option to adjust the house designs. These options come in floor layout, paints and colors, materials, kitchen appliances, and the like. Meeting the customer
demand in this way requires trial-and-error, reconfiguration and recalculation of materials and costs (Anebyhusgruppen, 2022), thus, affecting the business of prefabrication and their efforts to be resource efficient. The levels of customization that prefabrication can accommodate is undefined, leaving both the customer and the company being mutually frustrated.

The terms that are commonly used in this study are defined and put into context:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>prefabrication</td>
<td>The process of building parts in an off-site location, before being transported and built in a site</td>
<td>Jensen, P. et al. (2008)</td>
</tr>
<tr>
<td>modularity</td>
<td>The concept of cutting parts of a whole for easier assembly or disassembly</td>
<td>Battaïa, O., Dolgui, A., Heragu, S., Meerkov, S., &amp; Tiwari, M. (2018)</td>
</tr>
<tr>
<td>customization</td>
<td>The concept of personalization and uniqueness to one's needs and desires</td>
<td>Bardakci, A. and Whitelock, J. (2003)</td>
</tr>
<tr>
<td>house model</td>
<td>A complete design of a single house that is one among many products of a house manufacturing company</td>
<td>Anebyhusgruppen (2022); author</td>
</tr>
<tr>
<td>House manufacturer, prefabricated house company</td>
<td>The company that sells prefabricated houses as a core product; the company with a design office and production warehouse</td>
<td>Anebyhusgruppen (2022); author</td>
</tr>
<tr>
<td>Building Information Modeling (BIM)</td>
<td>A digital process and a tool in managing information of a built structure; used in the architecture, engineering, and construction (AEC) industry</td>
<td>Azhar, S. (2011)</td>
</tr>
</tbody>
</table>

Table 1. Glossary of terms (various references; author).

1.1.1 Project Description

The project is an investigation of the customization requirements in the prefabricated house business in Sweden. It includes how architectural design is a means to communicate to customers and meet their needs. The project covers the current industry practice and the challenges that are faced by the increasing demand for customization. It also discusses the
interdisciplinary nature of the prefabrication industry which puts together business, engineering, and design.

This study is conducted in conjunction with a case project and case company. The case project follows an innovation process and it is divided into three phases: ideation, realization, and implementation. The case company in this study is used as a reference to the industry business model. The project’s case company and collaborator is Anebyhusgruppen AB, a company in the prefabrication industry and is one of Sweden’s oldest wooden house manufacturers that was established in the year 1988.

The study concludes with a criteria for customization that is applied in a house model. This proposal complements the business model of prefabricated houses in Sweden and motivates similar research on prefabricated houses in the various social contexts.

1.2 Relevance of the Study

The study puts forward innovation where it is relevant to a household and to a personal level. It aims to effectively encourage sustainability starting from the choice of human shelter – the house. Thusen & Hvam’s (2011) study revealed that the 30% is reduced in product cost because of prefabrication of houses. Due to this reduction, prefabricated house companies are able to sell houses to customers who will not be able to afford it at a higher price range. This supports the Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities, stating:

“by 2030, ensure access for all to adequate, safe and affordable housing... and enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management” (UN, 2022).

The continued innovation in the prefabricated house industry will allow it to maintain its sustainability efforts while accommodating the customization needs of customers.

The customization capacity was not a concern of the industry when it started. During the early years of the prefabrication industry, in the 1960’s, the customer demands were low and the
requirements for the architects’ technical approach was standard (Höök, 2005; Jensen, P. et al., 2008). Today, there are two paths to choose from for customers who want to build a house: either choosing a fixed design, or ‘house models’, or the more flexible option of hiring an architect to come up with a design then hiring a builder to construct (Wikberg, F., Olofsson, T. & Ekholm, A., 2014). Customers are drawn to the concept of the former, prefabrication, because the cost of construction and the house design are presented upfront, in the early stages of the project.

These companies in Sweden are now faced with customer demands that increase the time that is demanded in the design process. The research for addressing these customization needs in the construction and house building industry are currently sparse (Nielsen, K., Brunoe, T., Jensen, K., & Andersen, A., 2017) and therefore limits the innovation possibilities in this area. Similarly, these changes challenge the company’s manufacturing capabilities. These demands are addressed with solutions that are project-specific and do not fit the production system, thus, causing low productivity and strain to the business as a consequence (Jensen, P. et al, 2008; Lessing, 2006).

1.3 Purpose

The purpose of the study is to map the customer demands that challenge the customization of prefabricated houses and to develop a criteria for house customization through architectural design and architectural BIM technology. To successfully do so, the research questions are:

1.4 Research Questions

What causes strain in the customization process of prefabricated houses?

How can Swedish housing prefabricators develop the value of customization for their company and their customers?

1.5 Scope and Limitations

The study is developed with discussions on the multidisciplinary nature of the prefabrication industry. The point of innovation is identified in the architectural design process and aims to extend and encourage further studies related to customization and modularity.
1.5.1 Delineation of Field of Study

The discussion on prefabricated houses in Sweden is investigated through the lens of architecture. Architecture and architectural design in this study is discussed as the arrangement of spaces in the socio-cultural setting of the house. Architecture is also used to design experiences within the spaces of the house. The challenge of customization is highlighted as the strain on the architectural design process and how architectural design plays an essential role in streamlining the business process. Within architecture, the study integrates technology through BIM as a tool for designing and communicating to customers and other stakeholders. The business and engineering aspects serve as reinforcing fields of study that are vital in understanding the multidisciplinary nature of the study while maintaining the focus on design.

1.5.2 Delineation of the Project

The business model of prefabrication in Sweden that is investigated in this study is a model involving 3 segments: the design office, the warehouse, and the construction site. The investigation is covers these 3 parts that are under one management and one brand, such that of the case company.

The design case project at hand is a house model or a whole structure that is available in the market for purchase. This study makes use of the house as a visual representation of the design process and the communication between business and customer. The house model is also integrated in the BIM systems that is discussed in this study.

1.6 Report Outline

This overall report is divided into the: (1) conceptual study and the (2) case project. The conceptual study discusses the theories and applied methods around the prefabricated house industry in Sweden. The case project on the other hand, is a practical application of the conceptual study and the prototype for the proposed approach to customization. These two parts are then analyzed together in the end to form the discussion and conclusion. For project planning information, see appendix 1.
A study framework was developed to show this intent:

Figure 1. A study framework consisting of a conceptual study and case project (author).

The structure is as follows:

**PART 1**

*Chapter 1*, Introduction, starts by discussing the topic of prefabrication and the industry situation in Sweden. The concepts and terms that will be used throughout the study are also presented. The challenges of customization are brought up in this chapter to build up the relevance of the study and research questions. Afterwhich, the scope and limitations of the project are discussed.

*Chapter 2*, Theoretical framework, dissects the concepts of *mass production,* *design customization,* and *customer satisfaction,* which are the core discussions in the study.

*Chapter 3*, Methodological framework, covers the design research process in 3 phases, *ideation,* *realization,* and *implementation.* The different methods are described along with an ethical consideration of the study.
TRANSITION

Chapter 4, Contextual analysis, links the conceptual study and the design case project. This chapter starts with the empirical findings. It presents the information from interviews and the comparative analysis methods that were performed. This information is then put into context in the rest of the chapter.

PART 2

Chapter 5, Design case project, is a practical application of the previous chapters’ discussions. It is an investigation and modification of a 1-storey prefabricated house model. The project progression and proposed solution are presented in this chapter.

SYNTHESIS

Chapter 6, Conclusion, covers the course of the study that led to the answers to the research questions, the encountered limitations, future research and use of the study, and project reflections.
2. Theoretical Framework

*This chapter covers the multidisciplinary concepts in the Swedish prefabricated house industry that will be the framework in addressing the challenges in customization.*

The first section discusses the engineering concept of *prefabrication*. The second section contains the design concept of *customization*. The third and final part discusses *customer satisfaction* as the business component.

2.1 Prefabrication

Prefabrication is the production of components in an off-site location or a warehouse, then transported to the construction site for assembly (Tavares, V., Lacera, N., Fausto, F., 2019). According to Tavares et al. (2019) and Kamali, M. & Hewage, K. (2016) there are different types of prefabrication, here in Table 1:

<table>
<thead>
<tr>
<th>Type</th>
<th>Parts/scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component manufacture</td>
<td>Windows, doors, equipment</td>
</tr>
<tr>
<td>Non-volumetric pre-assembly</td>
<td>walls and timber trusses</td>
</tr>
<tr>
<td>Volumetric pre-assembly</td>
<td>Toilets, bathroom pods</td>
</tr>
<tr>
<td>Modular building</td>
<td>Complete built units that compose the whole building</td>
</tr>
</tbody>
</table>

With these types, different degrees of prefabrication can be developed within the controlled off-site production. As the level of prefabrication increases and less custom requirements, the use of materials and energy decreases (Tavares et al, 2019).
This concept aims for cost-efficiency in controlling time and resources. In the context of prefabricated single houses, those who want to build a house can choose from a wide range of fixed house designs that are marketed to be less expensive than independently designed and built houses (Tavares et al., 2019; Anebyhusgruppen, 2022).

Closely linked to prefabrication is the concept of mass production as the process of producing quantities of a template and fixed design (Radder, L. & Louw, L., 1999). This concept is best exemplified by the car industry where customers are offered with the fixed car models that are sold in the market. For personalization, customers may choose a color among a few predetermined options. Mass production is also evident in the clothing industry where a design is given a size category (small, medium, large), to fit a customer better. This concept is in line with the goal to produce faster and in quantity. In the housing industry, with prefabrication, customers
are presented with a range of house models with the hopes that their needs will be met by a single predetermined house model.

2.1.1 Product Development in Prefabrication (PDP)

The house construction industry is conventionally project-specific and has evolved to adopt the product manufacturing concept of standardization (Jensen, P. et al., 2008). The *house construction* and *product manufacturing* concepts have merged to become the *house manufacturing* business with the aims of putting together the practice of construction and the efficiency aspects of manufacturing. The house manufacturing industry today has established an assembly-line process of: (1) prefabricating the house parts in factories to be (2) transported later and (3) assembled at the construction site (Jensen, P. et al., 2008).

![Diagram of Construction domain vs. manufacturing domain](image)

*Figure 4. Construction domain vs. manufacturing domain diagram (Johnsson, H. et al., 2006)*

Product development in prefabrication sees its future in the manufacturing domain. The current scenario is, every new house project requires a whole new product development process to satisfy the customers' varying needs. Ideally, in the PDP process, houses can be viewed more as a mass product rather than an ever-changing unique design. House construction innovates in order to make the manufacturing process streamlined with a standard and central product development process and the customer needs could be translated into functions that do not require a whole new process of its own.
2.1.2 Modular Off-Site Production

Höök & Stehn (2008) described off-site production as a concept in industrialized housing when production is done in a fixed factory environment with the goal of doing only assembly in the construction site. This process is also performed by one owner with a clear aim of reproducing the same house design and production (Höök & Stehn, 2008). In the project’s case, the single owner is the house manufacturing company. See appendix 2 for other modularity and off-site techniques and their definitions as compiled by Larsen M., Lindhard S., Brunoe T., Nielsen K. & Larsen, J. (2019).

![Image](image)

*Figure 5. Modular off-site production (site visit by author).*

2.2 Design Customization

Customization is demanded by the housing market at affordable costs (Marchesi, M. & Matt, D., 2017). The customizability of a customer’s purchase gives the value of ownership and personality. Specific to the home, customers have preconceived notions of how their house should feel like and they have a personal choice for a wide range of factors such as materials, size, and furniture. In the building industry, customization is assisted by design tools and softwares. Among the many softwares for spatial design (architecture and interior design),
Building Information Modeling is the common concept that guides the software development and design process for architects and designers.

2.2.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) is the use of smart graphics and data incorporation in models to come up with building designs and solutions. It uses software with 3-dimensional modeling and embedded information per component to aid project coordination. It is a single platform of integrated and multi-operational information that are essential in decision-making in the building industry (de Souza, F., 2006). Figure 6 shows the participation of BIM throughout the building cycle from design, building, and operation.

![BIM Diagram](image)

*Figure 6. Use of BIM throughout the building cycle (Bohrim, 2020).*

The technology is rapidly evolving and the building sector is continuing to innovate their businesses along with BIM. It has been adopted by the manufacturing industry to continue their growing productivity that has been faster than that of the construction industry, according to the Construction Industry Institute (de Souza, F., 2006). Veenstra, V., Halman, J., & Voordijk, J. (2006) argued that utilizing a platform-based approach has been proven to balance standardization while at the same time accommodating variety and customization in different
industries. To facilitate customization, there has to be a communicating platform that will be used across the departments of an organization. BIM helps designers and other users to communicate technical data across many platforms as it enables a model to carry the information that is needed in design, quality assurance, construction, and building maintenance.

2.3 Customer Satisfaction

Customer satisfaction rests on choice. For a company to be effective, it is vital that the intent of the product matches the identified customer needs and that these needs are translated into choices that are well communicated (Winther Dahl & Floreanaes, 2016). It is important to consider the behaviors of the customers and cater to their future needs (Solomon, M., Bamonssy, G., Askegaard, S., & Hogg, M., 2016). The discussion on choice initially conflicts with the concept of mass production and fixed design. Prefabricated house companies aim to achieve low production costs and at the same time be able to offer customization in their house models. In order to achieve this, mass customization is applied.

2.3.1 Mass Customization

Mass customization is a manufacturing concept that accommodates customization and personalization with a cost that is close to mass production (Larsen M., Lindhard S., Brunoe T., Nielsen K. & Larsen, J., 2019). It is the use of scale to secure a low cost of production whilst not foregoing the customization feature (Barman & Canizares, 2015; Jensen et al., 2017). Mass customization creates the value of personal attachment and the effect that customers designed the product themselves (Franke, N., Schreier, M., & Kaiser, U., 2010). Due to this, customers are willing to pay extra for a product that is customized (Franke et al., 2010). Even then, Berman (2002) discusses that design flexibility is limited in the concept of mass customization compared with processes that are engineer-to-order that perform production in repetition and scale (Berman, 2002). Frutos & Borenstein (2003) says that mass customization is highly applicable in the prefabrication sector because customers demand personalization. The challenge for companies that aim for mass customization is addressing all customer needs while staying within their company’s capabilities (Du, X., Jiao, J., and Tseng, M. M., 2006). Apart from the challenge of working within company capabilities, customer satisfaction and determining project success
are complex to measure because of its subjective nature. The most determining factors of success in mass customization are meeting the deadline and working within the budget, which in turn, translate to customer satisfaction (Nguyen et al., 2004).

2.3.2 Means-end Value Chain

The means-end chain is a way to link customer values and product attributes. It is a series of correlations that turn the intangible client values into tangible product attributes. This is done through identifying product attributes, functional consequences, psychosocial consequences, and then the state of being that the consumers are trying to satisfy (Woodall, 2020).

![Figure 7. Means-end Value Chain (Woodall, 2020).](image)

According to Gutman, J. (1982), the proponent of the very first model, it aims to explain how a product or service options facilitate achieving the preferred end-state. It is based on two assumptions about consumers: (1) that values (desired end-state) play a dominant role in the act of choosing, and (2) that customers face a diversity of choices which they assess according to sets in order to ease the complexity of choice (Gutman, 1982). See appendix 3 for the original means-end chain model.
3. Methodological Framework

This chapter describes what, why and how a series of methods were used in intentional sequence to support the results.

3.1 General Framework

A conceptual study is complemented by a design project with an innovation process of 3 stages - ideation, realization, and implementation. This follows Curedale’s (2019) model of design thinking: ‘discover’, ‘define’, and ‘develop’-stages. The intended outcome of this methodology is to link the conceptual nature of the study to a design case project. To show the progression of the project, the methods are sequenced according to which phase they were implemented. The methods were meant to intersect and complement each other to form discussions that are necessary to deepen the reflection and data analysis (Curedale, 2019).

3.2 Information Gathering and Problem Definition

The information gathering started with literature review and digital web search. This allowed the study to be well-informed in the areas of prefabrication and the business of prefabricated housing in Sweden. The first search words and terms were ‘prefabrication’, ‘prefabricated houses’, ‘prefabrication in Sweden’, and ‘customization’. After obtaining general information of the subject, in-depth information gathering was conducted through field visit, interviews, and comparative analysis. See appendix 4 for the initial context identification through the who, what, why, where, when, and how questions.
3.2.1 Field Visit

A field visit is an evaluation technique in the form of observation. The conducted visit is a way of first-hand data collection (Lawrenz, Keiser & Lavoie, 2003) that enabled the researcher to see the industry of prefabricated houses in three settings: the office, the warehouse, and the construction site. The field visit was interactive and the researcher had the opportunity to ask questions from individuals with different work roles such as architect, marketer, and warehouse manager. Aside from spontaneous dialogues, interviews were scheduled in between field visits. See appendix 5 for more images of the field visit.

Figure 9. Warehouse field visit (author).

Figure 10. Construction field visit (author).
3.2.2 Interviews

Unstructured interviews with members of the case company were conducted during the field visit. The intent was to understand the business environment and to know the process and challenges of customization in the interviewees’ respective points of view. An unstructured interview is an approach that extracts the interviewee’s own understanding of a situation in their social setting (Bryman & Bell, 2015). In this setting of a company structure, the study aims to get multidisciplinary perspectives and data about the intersections of the different departments along with their roles in the identified challenge of customization. The unstructured interviews were in casual and conversational nature (Bryman & Bell, 2015) that started with the prompt research question: ‘What causes strain in the customization process of prefabricated houses?’

<table>
<thead>
<tr>
<th>Design and Management</th>
<th>Production and Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketing manager</td>
<td>Builder</td>
</tr>
<tr>
<td>BIM systems specialist</td>
<td>Warehouse manager</td>
</tr>
<tr>
<td>Design team manager</td>
<td></td>
</tr>
</tbody>
</table>

*Table 2. List of interviewees; varying work roles within the housing industry (author).*

3.2.3 Comparative Analysis

The comparative analysis method was used to see how the different house manufacturers approach customization. This method was used to understand the market positioning of this study’s case company and identify its strengths and weaknesses. It serves as benchmarking and a way to present existing solutions in Sweden. This also makes the study understand customization in an industry level and not only focused on the case company that is presented here. Grasping the existing solutions in the industry and understanding the case company’s positioning gives an informed assessment of the potential solutions to the identified problem (Ulrich & Eppinger, 2015). The information on the different house manufacturing companies and the house models they offer can either be found on a company website or a catalog with in-depth information of the process of building a house. For the purpose of the research, 3 house catalogs were ordered to compare marketing strategies and first-hand experience of inquiry as a customer.
3.2.4 Customer Journey Mapping (CJM)

A customer journey map is a visual representation of the sequential interactions and events that a customer experiences with a service provider (Rosenbaum, M., Losada, M., Ramirez, G., 2017). The use of the customer journey map in this study was to visualize the flow of customer engagement in the prefabricated house industry.

Figure 11. Photo of catalogs from 3 different house manufacturing companies (author).

Figure 12. Customer journey map - business perspective (Anebyhusgruppen, 2022; author).
After which, the pain point was identified as the point where there is a strain in addressing customization. This pain point in the customer journey map is then translated into the point of innovation that becomes the basis of the case project. The point of innovation later on addressed the research question: ‘How can Swedish housing prefabricators develop the value of customization for their company and their customers?’ The customer journey mapping was established after the interviews were conducted to ascertain varying customer experiences.

Figure 13. Customer journey map - identified bottleneck (Anebyhusgruppen, 2022; author).

3.3 Ideation Phase

The ideation phase is the first attempt to narrow down the challenge of customization to its root causes. Brainstorming on the current situation and discussing the stakeholders were the methods that were implemented.

3.3.1 Brainstorming

Brainstorming is a method of extracting multiple ideas in a free-flowing manner (Cross, 2000). The participants were given a prompt question or statement that encourages a quantity of ideas. The brainstorming that was done in the ideation phase of this project is a problem definition activity by the researcher as a facilitator and the case company. With the prompt “Challenges in customization”. Both parties had to come up with 10 questions related to the prompt in a
duration of 10 minutes. After which, the questions are discussed to see the most pressing concerns, similarities and differences. The questions were also encoded in a word cloud software to highlight keywords and a hierarchy of concerns. This gave a common ground on what research area will be most valuable to the industry.

![Word Cloud Example]

**Figure 14. Brainstorming and word association between researcher and case company (author).**

### 3.3.2 Stakeholders Map

The stakeholders map is a visual representation of all the participants in a given scenario or setting, in this case, the prefabricated housing industry. Listing down the active stakeholders was key to getting a broad perspective on the subject at hand. The stakeholders were identified by their role in the identified problem (Curedale, 2019) in the fields of business, engineering, and design. The stakeholders map is developed with the case company in the context of Sweden and the study as a research and development (R&D) participant.

![Stakeholders Map]

**Figure 15. Stakeholders in a multidisciplinary perspective (author).**
3.4 Realization Phase

The next phase, realization, highlights the design project. Here, a house model is chosen and investigated to perform an applied research.

3.4.1 Design Case Project

A case study aims to evaluate and analyze concepts in a given specific context (Crowe, S., Cresswell, K., Robertson, A. et al., 2011). It gives an in-depth discussion in multi-faceted approaches to complex issues with a real-world application. The case study presented here is an evaluation and analysis of the identified challenges in customization. A list of challenges from different stakeholder perspectives led to a criteria of customization and used as applied research to a house model. The case study, also the design case project, is deeper discussed in Chapter 5.

3.5 Implementation Phase

This phase proposes the design to the industry by inserting it in a virtual 3D modeling representation. Design softwares is used in the field of architecture and manufacturing to visualize designs and to achieve quality assurance. Technology integration through BIM is put forward as a means of implementation and communication for the solution.

3.5.1 Technology Integration through BIM

Building Information Modeling is a digital process and a tool in managing information in a built structure; used in the architecture, engineering, and construction (AEC) industry (Azhar, S., 2011). The developed criteria from the case study is applied in a house model in a digital environment and is intended to be used in the design process of the company with the support of their in-house software. For the purpose of this study, the software that is used is Graphisoft Archicad.
3.6 Ethical Considerations

This thesis work is produced with a case company, Anebyhusgruppen AB, who has shared expertise and information that are relevant to the goals of the study. The role of the company as collaborator included confidential information and proprietary data, therefore, a non-disclosure agreement was established between the researcher and a representative of the company. Some data are excluded from the manuscript, however, were presented as descriptions that do not violate confidentiality. Ethical considerations likewise apply to the interviewees who were informed of the purposes of the interviews and whose data that were gathered are mentioned with consent.

After laying out the components of the methodology, the following chapter presents the contextual analysis.
4. Contextual Analysis

This chapter starts with the empirical findings from the field visit, interviews, and comparative analysis. This is followed by describing the formed context and foundations of the design project.

4.1 Levels of Customization

The field visit and interviews gave first-hand information that is specific to the environment and the roles of the interviewees (Lawrenz, Keiser & Lavoie, 2003). Initially, the unstructured interviews led to discussions of different topics. Customer choices and the concept of customization was discussed on these different scales:

1. number of house models;
2. kinds of house models;
3. the separation of spaces within the house;
4. materials used for construction;
5. materials used as paints and other finishes;
6. electronic installations (ie. oven, microwave, lights) and furniture (ie. chair, table, bed).

The discussions included intangible areas of concern which are:

1. marketing and selling efforts;
2. design management among architects;
3. method of construction;
4. warehouse capabilities.

The first challenge in data gathering was sorting through the customization challenges and categorizing the requirements of the customers. With the goal of identifying the most strained area of customization, the first step was to categorize the requirements according to scale and then defining the scales as ‘tiers’. Through a series of discussions, a hierarchy of customization was developed:
Tier 1, Brand: There are different brands in the prefabricated housing industry. These brands have a similar general business model of having an in-house designer, own warehouse, and own management structure. Customers start the process by looking through the different house manufacturing companies with the hopes that their ‘dream house’ is among the house models that are in the market. Which company to work with is the first choice a customer makes.

Tier 2, Structure: Each brand has a set number of house models to choose from. These start with the house type: 1-storey, 1.5-storey, 2-storey, slope-house, semi-detached house, and
accessory structure. This choice is made by the customer according to their lot type and the number of people who intend to live in the house.

**Figure 18. Kinds of house configuration (Anebyhusgruppen, 2022).**

**Tier 3, Module:** Modules are the different rooms in a house that are built through external and internal walls. The walls are the biggest part of the house that is prefabricated in the warehouse and the most adjusted component when the customization requirement is adjustment in the arrangement of rooms and floor layout. The major areas in the house are the living room, kitchen, and dining area. More specific to customer needs are the number of bedrooms according to their household setup. Customers also look at their living situation for 5-, 10- years and inquire about the flexibility of their purchase after they have built it.

**Figure 19. Arrangement of rooms in a floor plan (Anebyhusgruppen, 2022; author).**

**Tier 4, Fixed Unit:** Fixed units are the components and material finishes that are fixed in place such as tiles, and paints. Doors and windows are included in this tier as a customizable fixed component on walls. This tier comprises the most choices for customers with aesthetic and
personal preference as the main factor for selection. Materials also vary in price according to the marketed value that ranges from simple to luxurious.

**Tier 5, Movable Unit:** These are the movable furniture in the house such as chairs, tables, and bed. These units seldom influence the manufacturing process because of their independence from each other. In most cases, the selection and purchasing of furniture are done by the customers independently.

### 4.2 Customization Challenges

The challenges that were discussed vary through different industry roles while more pressing challenges such as manufacturing was expressed as a collective strain of the company. The identified customization challenges were analyzed along with the designated tasks performed by individuals. The industry role, tasks, and identified customization challenges are:

<table>
<thead>
<tr>
<th>Industry role</th>
<th>Tasks</th>
<th>Customization challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td>- Design house models</td>
<td>- Repeated revision of design</td>
</tr>
<tr>
<td></td>
<td>- Modify changes that are requested by customer</td>
<td>- Client demand that are outside the house model design</td>
</tr>
<tr>
<td></td>
<td>- Evaluate houses in terms of space efficiency</td>
<td>- Staying within construction budget</td>
</tr>
<tr>
<td></td>
<td>- Compliance to building code</td>
<td>- Time constraints</td>
</tr>
<tr>
<td>Office Management</td>
<td>- Streamline warehouse, office, and construction site</td>
<td>- Conflict management between designers and builders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Coming up with a company standard and approach to customization demands</td>
</tr>
<tr>
<td>Builder</td>
<td>- Quality assurance</td>
<td>- Trial-and-error in the off-site manufacturing</td>
</tr>
<tr>
<td></td>
<td>- Meeting the deadline</td>
<td>- Time constraint</td>
</tr>
<tr>
<td></td>
<td>- Following the design</td>
<td>- Materials waste</td>
</tr>
<tr>
<td></td>
<td>- Efficiency in construction</td>
<td>- Quality kept in check</td>
</tr>
<tr>
<td>Marketer</td>
<td>- Marketing communications with customers</td>
<td>- Communicating limitations</td>
</tr>
<tr>
<td></td>
<td>- Selling the value of the house models</td>
<td>- Selling the house models without revision</td>
</tr>
</tbody>
</table>

*Table 3. Customization challenges for stakeholders in the Swedish housing industry (author).*
Among the tiers, the most challenging to customize is tier 3, the module. Changing the configuration of the floor plan affects all parts of the house such as utility lines and ceiling terminations. A request to change the space layout also means that the house model will be a unique house to which the warehouse production would have to adjust custom settings. According to the warehouse manager, it is best if the walls are kept the way they were first designed and if they come in similar lengths within the structure. For example, 8.5 meters and 12 meters are usual wall lengths for many house modules. From this customization challenge came the idea of the grid system. This is an architectural element where walls are placed almost within the same horizontal or vertical axis to ascertain wall lengths and continuous space flow.

With the challenge of customizing tier 3, tier 2 (structure) is the focus of most prefabricated house companies. The house models give the first impression to the customers and this gives them at least 10 options of model houses per brand (tier 1). The complexity of choice is evident from the start and this is addressed through marketing and communication efforts.

The clients are presented with a multitude of options from the levels of customization. With all these options, it is the in-house architect that is at the receiving end of the strain to revise drawings. It becomes apparent that the criteria for customization has gaps when it comes to what to allow and what to reject.

4.3 Existing Solutions

**Exterior customization**

An option is being offered where customers may choose the exact same house model and floor plan and be able to change the look from the outside. This could be from wall paint, outer wall material, roof, and doors and windows. The most common exterior customization options are modern or classic. This targets customers who might have already found a floor plan that suits them but are particular with how their house looks from outside. This is an advantage in the prefabrication industry because this customization requires minimal adjustment in the manufacturing process.
Model variation

Most companies have a select number of house models that have a predetermined variation to the model— a version 2 or 3. This could be a space that is interchanged, for example a bedroom that can be an office. It could also be interchanging locations of bathroom and laundry. This is also considered a minimal case of customization since the variation has been assumed and therefore means that the manufacturing is capable of the changes.

List of material finishes

One of the closest to the personalization and customization experience of the customers are the material finishes, colors, textures, and overall aesthetics of the house. The house manufacturers present a wide range of material and paints and offer construction methods that suit their capabilities. Appliances and fixtures are also presented for preferences of simple to luxurious.

Bare house model

Amongst all the options available, there is always a standard bare house model which is marketed as simple and affordable. This targets smaller and more practical construction budgets. It is marketed as a bare house model that welcomes customization upon move in - may it be in decoration or choice of furniture.

Others

Other existing solutions include grouping the model houses according to their value, assuming a variation of at least 3 types – simple, semi-customizable, and unique houses. The simple houses are basic in layout and finishes, the semi-customizable are those with variations, and the unique houses are for the clients who are willing to spend on heavy alterations and customization within the design.

4.4 Comparative Analysis

The comparative analysis of the house models is among 3 house manufacturers who cater to clients in the similar vicinity in Sweden.
Table 4. Overview among 3 different house manufacturing companies (author).

<table>
<thead>
<tr>
<th></th>
<th>House manufacturer 1</th>
<th>House manufacturer 2</th>
<th>House manufacturer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value proposition</td>
<td>Optimal living</td>
<td>Welcome home</td>
<td>We help you build your dream house</td>
</tr>
<tr>
<td>Number of house models</td>
<td>~38</td>
<td>~59</td>
<td>~53</td>
</tr>
<tr>
<td>1-storey, 2-storey, 1.5-storey, and slope house</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Duplex</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Accessory (garage/extension)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3D tour online</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Price online</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Upon browsing through the catalogs, the offerings initially feel the same— a variety of house designs, only with the overwhelming amount of options. Across all the manufacturers, the house models are easily filtered through the option of 1-storey, 2-storey, 1.5-storey, and slope house. Some manufacturers offer more building types than others and some of bigger scale. The scale of what they offer matches their warehouse capabilities and logistics strategies.

After looking at the catalogs, the company websites were observed. House manufacturer 2 displays more minimal design and less house model options on the homepage of the website. House manufacturer 3 presents all its model houses and shows numbers such as floor area, number of rooms, and plans. House manufacturer 1 seems to be in between, but focuses mostly on expressing the customization possibilities. The marketing and communication effort through a website gave a stronger impression than the catalog. Through the website, the 3D images of the houses can be seen and rotated in real-time. Seeing the house in 3D and in simulation gives an added value in understanding the space compared to the 2D representations in the catalog.
Through the website, the companies are able to communicate using the emotional value and functional sequence (Woodall, 2020) and invite the customer to choose based on the lifestyle they project. Examples of these statements are “your dream house”, “a home that is one with nature”, or “for a bright future”. Communicating the experience that is expected allows the customers to associate themselves with a space layout or type of house. This emotional and psychological value is what the point of innovation is targeting that will be the guide in decision-making in customization.

4.5 Customization Criteria

To come up with the criteria for customization, the means-end value was utilized. The communicated client motivations and values were tabulated and translated into attributes or actual space requirements.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Functional Consequence</th>
<th>Psychosocial Consequence</th>
<th>Value</th>
<th>House Model Design Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-plan design</td>
<td>Personalized to the user</td>
<td>Personalization, flexibility</td>
<td>Freedom</td>
<td>Continuous living room, dining room, and kitchen</td>
</tr>
<tr>
<td>Multi-functional room</td>
<td>Spaces can be interchanged</td>
<td>Self-expression</td>
<td>Longevity; long-term living</td>
<td>Allotment of a room apart from the bedroom, for personalization</td>
</tr>
<tr>
<td>Additional bedroom</td>
<td>Comfort</td>
<td>Privacy</td>
<td>Longevity; long-term living</td>
<td>Floor area that allows for a room addition within the</td>
</tr>
<tr>
<td>Current Structure</td>
<td>Flexibility</td>
<td>Proximity; control over own time</td>
<td>Accomplishment</td>
<td>Visual and auditory barriers through interior walls</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-------------</td>
<td>---------------------------------</td>
<td>----------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Work-from-home setup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modular and grid</td>
<td>Stability</td>
<td>Economic</td>
<td>Smart; practical</td>
<td>Efficient interior wall positioning</td>
</tr>
</tbody>
</table>

*Table 5. Means-end value development (author).*

The expressed personal values of the customers are:

1. Freedom of choice and personalization,
2. Longevity and being able to see how the house will evolve in the future, with a change in family set-up, 5- or 10 years later,
3. Accomplishment and being able to work in their personal space,
4. Smart construction and practicality in the choice of materials.

These were translated into attributes of open plan design, multi-functional room, additional bedroom, work-from-home setup and modular house design. These attributes along with the functional and psychosocial consequences translate into a **house model design criteria** that ascertains a depth in customization within one house model.

**Criteria:**

1. Continuous living, dining, and kitchen area;
2. Allotted room for personalization
   (ie. art room, library, music room);
3. Allotted space that can be subdivided with another room
   (ie. bedroom, office);
4. Visual and auditory barriers for privacy;
5. Efficient wall positioning (anticipating future configurations).
5. Design Case Project

Having dissected the challenges in customization, the study transitions to a design project. A typical house model will be redesigned to a new house model with maximized customization. A house model increases its value when the customers see that they can customize, personalize, and that the house can accommodate their future needs. The design project suggests a depth more than breadth approach in the amount of house models to choose from.

In the ideal scenario, there is one house model that has multiple interior layouts to accommodate present and future needs of the customers. In this way, the customers are assured that their future needs are anticipated. At the same time, the manufacturing will have the same process for the prefabricated house structure, with least changes in the walls within the house.

To apply the depth of this ideal scenario in a real-life house model, the chosen house for the case project is a 1-storey house with a basic L-configuration. This straightforward design makes analysis and visualization simple for the purposes of the study.

5.1 House Magnolia

House Magnolia (Anebyhusgruppen, 2022) is one of the many house models that is available in the prefabricated house market. It is a 1-storey house with 3 bedrooms, kitchen, dining room, living room, common room, laundry area, and 2 toilet-and-baths.

Figure 20. House Magnolia model - classical design (Anebyhusgruppen, 2022).
This layout was reviewed and examined to see its potentials for customization. See **appendix 6** for sketches of the analysis.

*Figure 21. Magnolia floor plan (Anebyhusgruppen, 2022).*

The 2D floor plan was drawn and modeled to 3D through an architectural BIM software. Specific to the study, Graphisoft Archicad was used for more accurate encoding and visualization. The use of this software automated the calculation of spaces and sizes that are needed to follow the building guidelines. Focus was given to modularity, space flexibility, and accessibility design and ease of circulation for a wheelchair. *Figure 22* shows the floor plan that was tested in different layouts and reviewed alongside each other.
Through Archicad, the first criteria that was implemented in the floor plan is the optimization of interior walls. Here, the original floor plan is put beside the proposed new floor plan with less interior grids. This gives the house model less wall modules that eases the manufacturing process.
The next solution is identifying the flexible space. The kitchen, living room, and dining area, along with the common room is in an open plan layout. This open plan layout allows the customer to put partition walls or leave the space open depending on their comfort.

![Figure 24. Identified flexible space (author)](image)

The open plan invites customization through furniture placement. With this, the customer has full control over the common spaces of the house without having to decide the exact room divisions upfront. The customer has the freedom to change the layout of the space as the household setup changes in the future. This layout likewise accommodates future change in lifestyle through flexibility of an open plan.

The series of floor plan reviews led to the final proposal: **House Magnolia PLUS**.

### 5.2 House Magnolia PLUS

This model is a proposal of a prefabricated house model with predetermined customization options focused on spatial layout. This house has multiple interior layout options that customers can choose from or could evolve as the household needs changes in space layout after it is initially built. The intent is that all these changes and room additions can be done without needing a structural renovation on the overall house shape. The proposed layout is based on the design criteria that fits the current shape and model of Anebyhusgruppen’s House Magnolia.
Figure 25. House Magnolia model - modern design (Anebyhusgruppen, 2022).

Figure 25 shows Anebyhusgruppen’s house Magnolia with a modern exterior look. The proposal in this project is a floor layout that complements this and its overall building shape. Seen in figure 26 is the proposed floor plan rendered in a 3D model.

Figure 26. Proposed space layout according to the design criteria (author).
Through BIM, the 2D simulation automatically builds the 3D and ensures accuracy in technical drawing and creative visualization. The use of 3D floor plan is for client communication and ease of understanding and maximized customer satisfaction. Figure 27 shows the 3D rendering in progress in Graphisoft Archicad.

Figure 27. BIM and rendering visualization  (author).

Figure 28. 9-space layout (author).
House Magnolia PLUS evolves through one’s household and lifestyle. Figure 28 - figure 31 show this transformation from a 9-space layout to gradually adding an office, a family room, and another bedroom—all within the same walls of the prefabricated house.

Figure 29. 10-space layout (author).

Figure 30. 11-space layout (author)
Lastly, a design solution that accommodates the requirements of: work-from-home, additional room, and multi-functional room. Scenarios that are presented here are an option of an office or library that may cater to a professional that is working remotely. A room suggestion is a library or study room for an academic or researcher.

Another suggestion is a nursery for a growing family. The room is situated beside the parents’ room and could eventually be a child’s bedroom.
Figure 33. Multi-function room - nursery (author)

Figure 34. Multi-function room - art room (author)
6. Conclusion

In this chapter, the main points from the design project along with the conceptual study are presented.

6.1 Conceptual Study and Design Project

There is added strain in customization due to (1) the complexity of choice in designing a house and (2) the mismatch between customer demand and manufacturing capability.

Through mapping the customer demands and proposing a design criteria, the model houses could have predetermined depth in customization opportunities. The customization process could be made more objective for decision-making.

Defining the depths of customization in tiers (tier 1-tier 5), makes it an objective process and allows for customer motivations to be extracted. A single house model that satisfies all tiers makes it a very customizable unit that does not require a huge change in the production process and gives the designers and manufacturing focused attention on quality assurance instead of meeting various demands in quantity.

The customization criteria encourages the standardization of processes within the organization and to strengthen the Building Information Modeling (BIM) efforts that are already in place.

Designing house models with predetermined future customization gives the product the added value of security for long-term adaptability. In addition to the value it creates for the prefabrication system, it also creates value for the model houses that the company presents. A house increases in value when the customer sees how it can evolve in the near future and in the next 10 years. The service that is provided by the company is long-term and gives the customers security that their purchase is a long-term purchase.
6.2 Limitations

There is only one house model that was used as a case study. Larger houses or 2-storey houses may be able to present more challenges in customization, and thus a longer criteria for design. The 1-storey house model was chosen to communicate a technical solution in the simplest way possible. Another limitation of the study is the duration of 5 months. The scope was kept to a scale that can discuss customization that is focused on architectural and spatial design. As the industry is multi-disciplinary, there are opportunities to take the study further in the directions of business and engineering as well.

6.3 Future Developments and Reflections

The study may be enhanced by investigating more house models and improving their layout for customization. Larger house models would have more customer demands and therefore need more customization flexibility.

Another path for future development is adding sustainability analysis in the BIM platform. In the growing interest in sustainability from customers, they can be more informed decision-makers if they can also choose their environmental impact based on how they build their house. This will be value-adding if customers are able to see the sustainability ratings of the changes they make in their house as early as the design phase.

If the customization criteria develops and will be effective, it can also influence legislation in the housing industry that encourages efficiency and sustainability while accommodating client needs.

The proposed customization criteria for the house model may also be adopted by other modular designs such as in social housing with more fixed modules. The presented depth in customization set a good standard in meeting more customer needs especially for prefabricated modules that address social design needs. This study encourages deeper understanding of customization in contexts outside of Sweden especially that the proposed solution is spatial in nature and may be explored further in house typologies in different countries.
House Magnolia PLUS is a one-storey prefabricated house with depth in flexibility and multiple layouts within the exact same walls. House Magnolia PLUS is an investment that grows with you as your household evolves through time. This is not a one-time purchase but a long-term purchase that anticipated your needs for the next decade and forward.
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## Appendix 1: Project planning information

### Task list per phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Output/Activity</th>
<th>Business</th>
<th>Eng’g</th>
<th>Design</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Data Gathering</td>
<td>Interviews</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
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<tr>
<td></td>
<td>Field visit</td>
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<tr>
<td></td>
<td>Comparative analysis</td>
<td></td>
<td></td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>Customer journey</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Literature review</td>
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<td></td>
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<tr>
<td>2. Ideation</td>
<td>Stakeholders’ map</td>
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<td></td>
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<td>-</td>
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<tr>
<td></td>
<td>Brainstorming</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>3. Realization</td>
<td>Case study (design project)</td>
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<td></td>
<td>-</td>
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<tr>
<td></td>
<td>Means-end diagram</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>4. Implementation</td>
<td>Building Information Modeling (BIM)</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Criteria through means-end diagram</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Evaluation interviews</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Overall presentation</td>
<td>Visual presentation</td>
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<tr>
<td></td>
<td>Written presentation</td>
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</tbody>
</table>
### Semester weekly schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Tasks</th>
</tr>
</thead>
</table>
| 4    | - Topic discovery  
    | - Context reading; literature review  
    | - Project proposal |
| 5    | - Problem definition workshop with Anebyhus  
    | - Software and BIM course (focus on prefabricated housing)  
    | - Review of model houses |
| 6    | - **7/2 LNU**  - Seminar 1 (Problem definition)  
    | - **9/2 LNU**  - Tutoring  
    | - Topic discovery cont.  
    | - Brainstorming (DT, AL, SD) |
| 7    | - **15/2 Company**  - Presentation 1  
    | - Data gathering  
    | - Finalize tutors (company + LNU)  
    | - Chapter 1 text start |
| 8    | - Software BIM course cont.  
    | - Outline of methods  
    | - Thesis chat with classmates (DT, AL, SD) |
| 9    | - **28/2 LNU**  - Seminar 2  
    | - **2/3 LNU**  - Tutoring (Project description + project plan)  
    | - Chapter 1 text cont.  
    | - Chapter 2 text start |
| 10   | - **7/3 Company**  - Presentation 2  
    | - Ideation tasks |
| 11   | - Review BIM component  
    | - Ideation tasks  
    | - Chapter 3 start  
    | - Thesis chat with classmates (AC, VK, MS) |
| 12   | - **21/3 LNU**  - Seminar 3 (Ideation)  
    | - **23/3 Tutoring**  
    | - Text review 1  
<pre><code>| - Design project backbone |
</code></pre>
<p>| 13   | - <strong>29/3 LNU</strong>  - supervisor meeting |</p>
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>31/3 LNU</td>
<td>Thesis draft 1</td>
</tr>
<tr>
<td></td>
<td>Realization tasks</td>
</tr>
<tr>
<td>8/4</td>
<td>Company - Check-in</td>
</tr>
<tr>
<td></td>
<td>Chapters 4-5</td>
</tr>
<tr>
<td></td>
<td>Realization tasks</td>
</tr>
<tr>
<td>11/4 LNU</td>
<td>Seminar 4 (Realization phase)</td>
</tr>
<tr>
<td>13/4 Tutoring</td>
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<td>2/5 LNU</td>
<td>Seminar 5 (Implementation phase)</td>
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<tr>
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<td>Text peer review</td>
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<td>9/5 Company</td>
<td>Presentation 3</td>
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<td>Thesis draft 2</td>
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<td>Presentation refinement</td>
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<td>24/5 LNU</td>
<td>mock presentation</td>
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<td>25/5 LNU</td>
<td>Thesis text for examination</td>
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<td>Examination</td>
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<td>Final presentations</td>
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Appendix 2: Modularity and off-site production techniques and their definitions. (Larsen M., Lindhard S., Brunoe T., Nielsen K. & Larsen, J., 2019)

<table>
<thead>
<tr>
<th>Off-site production technique</th>
<th>Definition</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularization</td>
<td>“... the preconstruction of a complete system away from the job site that is then transported to the site. The modules are large in size and possibly may need to be broken down in to several smaller pieces for transport ...”</td>
<td>Haas et al., 2000</td>
</tr>
<tr>
<td>Module</td>
<td>“A module is physically manifested as a construction unit that is part of a wider system, which can be integrated through pre-planned interfaces. These physical modules are the result of, and can facilitate, modularization in different phases of the project. They may be considered at different hierarchical levels within the overall product architecture, may be manufactured on or off-site, and can be volumetric or non-volumetric.”</td>
<td>Gooding et al., 2016</td>
</tr>
<tr>
<td>Off-site construction</td>
<td>“… the manufacture and pre-assembly of component, elements or modules before installation into their final location ...”</td>
<td>Goodier and Gibb, 2007</td>
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<tr>
<td>Pre-assembly</td>
<td>“… a process by which various materials, pre-fabricated components, and/or equipment are joined together at a remote location for subsequent installation as a unit ...”</td>
<td>Tatum et al., 1987</td>
</tr>
<tr>
<td>Prefabrication</td>
<td>“… a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation ...”</td>
<td>Tatum et al., 1987</td>
</tr>
<tr>
<td>Standardization</td>
<td>“… standardization is the use of the same component in multiple products and is closely linked to product variety.”</td>
<td>Urich, 1994</td>
</tr>
<tr>
<td>Industrialized housing</td>
<td>“… production in a closed factory environment where only assembly is performed at the construction site, with one evident process owner and a clear product goal of repetition in housing design and production ...”</td>
<td>Höök and Stehn, 2008</td>
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</tbody>
</table>
Appendix 3: Original means-end chain model (Gutman, 1986)
Appendix 4: Initial context identification through the *who, what, why, where, when, and how* questions (author)

<table>
<thead>
<tr>
<th>WHAT</th>
<th>WHEN</th>
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<tr>
<td>review the customization process of prefabricated houses</td>
<td>current and near future; with consideration of current building and environmental laws focused on wood construction</td>
<td>Sweden</td>
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<tr>
<td>efficiency and sustainability in time and materials</td>
<td>house manufacturing businesses</td>
<td>mapping customer requirements</td>
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<tr>
<td>streamlined design process</td>
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<td>making a customization criteria</td>
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</table>

<table>
<thead>
<tr>
<th>WHY</th>
<th>WHO</th>
<th>HOW</th>
</tr>
</thead>
</table>
Appendix 5: Site visit photos
Appendix 6: Layout analysis