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Changing business direction towards a more industrialized approach using modular construction

Master's thesis in Design and Construction Project Management

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MASTER'S THESIS ACEX30

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ABSTRACT

Modular construction has the potential to resolve many of the sustainability issues associated with the construction industry. It involves using prefabricated 2D-panels and 3D-volumetric modules for assembly in construction site to a complete building. However, the utilization of modular construction is limited and the challenges to implement modular construction are many due to the complexity it entails. Therefore, this report aims to define the process of modular construction, to identify the challenges involved and providing a roadmap of the fundamentals in the modular construction process that needs to be addressed for a successful implementation at traditional construction companies. A qualitative research approach with systematic literature review and interviews with experienced construction practitioners, representing organizations with different level of industrialized construction was conducted. The findings indicated the need of careful planning for a successful utilization of modular construction. An accurate control over the design phase is preferred to reduce errors, while the options for the manufacturing process provides a greater flexibility, albeit with different productivity as a result. As there are many different options to utilize modular construction, a solution to facilitate the implementation was suggested. It involves establishing a department for research and development to build the necessary infrastructure for the utilization of modular construction. The department should manage the labour needed by engaging employees from other department whenever needed for pilot projects. Employees joining the department is affected by the culture of industrialized mindset which simplify the change to having an industrialized way of thinking within the company. As the infrastructure mature, the department could reshape into having a similar role as IT departments, to further develop the infrastructure but also to support employees when necessary.

Keywords: Change management, industrialized construction, lean, modular construction, modules, sustainability.

Förändring av en verksamhet mot ett mer industrialiserat tillvägagångssätt genom modulär byggnation

Examensarbete inom masterprogrammet Organisering och ledning i bygg- och fastighetssektorn

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Avdelningen för Construction Management
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SAMMANFATTNING

Med modulär byggnation finns en möjlighet att lösa alla hållbarhetsproblem förknippad med byggbranschen. Modulärt byggande innefattar användningen av prefabricerade 2D paneler och 3D moduler som monteras till färdig byggnad på byggarbetsplatsen. Dock är användningen av modulär byggnation begränsad och utmaningarna är många på grund av den komplexa byggprocessen. Målet med den här rapporten är att fastställa denna byggprocess och de svårigheterna som förekommer, för att identifiera de beslut som behöver fattas för att förändra byggbolag med traditionella arbetsmetoder till att börja använda modulärt byggande. Rapporten bygger på en kvalitativ forskning med en systematisk litteraturstudie och intervjuer med experter inom byggbranschen som representerar organisationer med olika nivåer av industriellt byggande. Upptäckterna som gjordes under denna studie indikerade på att en detaljerad planering krävs för att på ett framgångsrikt sätt börja bygga modulärt. En noggrann kontroll över projekteringsfasen är ytterst önskvärt för att minska avvikelser och fel, medan tillverkningsprocessen är mer flexibelt emellertid påverkas produktiviteten av olika val. Då det förekommer många olika alternativ för att bygga modulärt, rekommenderades en möjlig lösning för att förenkla övergången till modulärt byggande. Den går ut på att en avdelning inom företaget upprättas med målet att bedriva forskning och utveckling för att skapa hela infrastrukturen som krävs för att bygga modulärt. Pilotprojekt drivs sedan av avdelningen, som även använder anställda från andra avdelningar inom företaget vid behov när dessa projekt bedrivs. Fördelen med detta är att de anställda som ansluter till avdelningen påverkas av den kultur som råder i avdelningen med ett mer industriellt tankesätt, vilket förenklar processen för de själva att förändra sitt sätt att arbeta. När den utvecklade infrastrukturen väl fungerar kan avdelningen skifta till att få en liknande roll som IT avdelningar brukar ha. Nämligen att fortsätta utveckla infrastrukturen men också att vara ett stöd för anställda som behöver hjälp i sina projekt.

Nyckelord: Förändringsledning, hållbar utveckling, industriellt byggande, lean, moduler, modulärt byggande.

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Preface

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A very big thank you to all the interviewees participating in this research. Despite the busy schedules, you have found time to share your knowledge, opinions and experiences. This report had not been possible without your participation.

I also want to show my gratitude to my family, friends and acquaintances. Thank you all for your kindness and understanding, especially with my occasional absence while working with this report.

Lastly, thank you for showing interest in my work. I hope you find it as interesting and rewarding to read as I found this topic to be while working with it.

1 Introduction

This chapter begins with some background information on why modular construction is a significant topic. Further, the aim and objectives of this report along with the delimitations are presented. Additionally, the ethical aspects of conducting this research and the effects of the findings are discussed. A guide over the structure of this report can also be found in this introductory chapter.

1.1 Background

Easily accessible resources in this planet are limited and resource depletion due to consumption risks reaching critical levels, leading to irreversible damages to ecosystems (Henckens, 2021). Especially with an expected increase both in total and middle-class population worldwide (O'Shea et al., 2013), in combination with a high urbanization rate, leading to an increased demand for constructions (Luo et al., 2021). In the European Union, an estimation of over 40 percent of the extracted material from natural resources is used by the construction sector, while the waste creation corresponds to around 40 percent of all waste generated (Mercader-Moyano & Ramírez-de-Arellano-Agundo, 2013). The choices and actions of the practitioners within the construction sector can, therefore, have a great impact on the total environmental footprint on this planet. Unfortunately, the construction sector is regarded as one of the most inefficient, with an annual global growth of 1 percent for the last 20 years (Razkenari et al., 2020). This is only a third of the total global economic growth and one-fourth compared to the manufacturing sector.

A consensus view of the construction sector is that it differs from other industries, mainly as a consequence of the complexity in the delivered product, in combination with the project-based arrangement (Barlow, 2000). Construction projects could involve many practitioners in different fields which temporarily collaborate to produce a product and ultimately dissolve when the end-result is delivered. Thus, the project-based nature results in short-term investments and loss of knowledge transfer in a company (Dubois & Gadde, 2002). As each project is evaluated separately, the focus is to improve the result for that specific project with little consideration on the impact of future projects. Consequently, innovations are not implemented in the same rate as other industries.

In the nineteenth century, the construction industry was regarded as a highly modern industry with impressive achievements, such as transcontinental railway and the Suez Canal (Winch, 2003). However, while other industries evolved through, for instance, utilization of interchangeable parts, assembly lines and automation, the construction sector has introduced innovations at a much slower pace. Modular construction could potentially play a big role to introduce the advantages obtained by other industries into the construction sector (Yu et al., 2013). With modular construction, a more industrialized approach can be obtained. Building components are considered as products which can be manufactured in factories, with the potential to mimic the manufacturing industry and obtaining the same kind of productivity benefits. These factory-made building components are then transported to the construction site for assembly to a complete building (Wasim et al., 2022).

The benefits with modular construction include reduced waste, increased productivity and improved work environment for workers (Bortolini et al., 2019). Hence, modular construction could result in reduced environmental footprint, cost reductions and improved social conditions. Sustainability can be considered as a goal, based on the three pillars, namely, environmental, economic and social factors (Bolson et al., 2022). This can also be simplified to cover issues regarding planet, profit and people. As modular construction has the possibility to improve all these three aspects, it has to be considered as a potential path to reach sustainable development. The implementation and utilization of modular construction in the construction industry is, therefore, an important subject to explore.

1.2 Aim of research

As industrialization of construction entails several advantages, a transition from traditional construction to a more industrialized approach could be a way forward for the industry to become more efficient and sustainable. The aim of this report is to identify possible ways for a construction company to shift their business toward a more industrialized procedure with an increased modularization mindset, but also to highlight the challenges involved.

1.3 Research questions

Due to the complexity of industrializing a business and to make the issue more tangible, the research questions presented in this section will guide the study to achieve the aim of the report. The intention with these research questions is to identify the differences between traditional and industrialized construction. Additionally, to find the necessary changes in order to transform a business into having a more industrialized approach. The research questions are as follow:

What changes are needed for a construction company to have a better utilization of modular construction?

How can these changes be implemented and what challenges are involved?

1.4 Delimitations

This study will focus solely on the industrialization of the building and neglect the procedure of constructing the foundation in which the building will be built upon. It is assumed in this study that the foundation is created without issue when the construction with the modules begins. The focus will also be on construction companies offering design-build contracts or turnkey contracts, which are companies with full responsibility to manage and deliver the whole project to the client. Furthermore, multi-storey buildings will be studied as these are deemed to have reached an interesting threshold between the use of traditional construction and modular construction. The report will emphasis on the Swedish construction market, however, international literature will be used and the results can still constitute relevance to other markets.

1.5 Objectives

The objective with this report is to identify possible way to improve the use of modular construction and, thus, increase the industrialization level of construction companies. The first research question, stated in Section 1.3, aims to serve as a guide to reach this objective. Further, the intention of the second research question is to highlight potential complications and challenges associated with modular construction. With the knowledge obtain from these two research questions, the ambition is to provide suggestion on potential direction a construction company could move towards, to reach a higher degree of industrialization.

1.6 Ethical aspects

A fruitful discussion on ethical aspects regarding a research would clearly be benefited by a clear definition of what ethics and ethical behaviours imply. However, as Pruzan (2016) stated, different cultures tend to assess ethics differently, making a fixed definition of what constitutes as ethical behaviours almost trivial. Pruzan (2016) believes this is the reason for scientific guidelines on ethical behaviours to focus on preventing unethical behaviours, rather than establishing them. Whether only avoiding unethical behaviours is enough to be considered as ethical actions is debatable, nevertheless, avoiding unethical behaviours could be considered as a minimum effort in the path to act responsibly. Nonetheless, ethics in research can be explored from two point of view, specifically, the ethical aspects regarding how the research was conducted and the ethical aspects with the intentions and results of the research.

The trustworthiness of a result derived from a research can be questionable if the researcher has secret motives, interfering and directing the result into a certain direction. In natural science, this phenomenon is limited by an objective research method, however, for qualitative research, there are some complications concerning the objectiveness of the researcher (Kazmierska, 2020). The researcher designs its study and even if the research object is treated objectively, it is still the researcher who selects which person to study. Hence, the objectivity can be questioned. To mitigate the uncertainties surrounding a research, it is important for the researcher to be transparent. The author of this report can declare no conflict of interest and conducted the research with an open mind without any conscious subjective intrusion on the result. The empirical research was conducted with voluntary participated interviewees which were informed about this research and kept anonymous due to prevailing regulations.

A study on industrialization of a sector could certainly be a sensitive topic, from an ethical perspective. Automation and robotization obviously can reduce the need of labour, with unemployment as a consequence. However, industrialization could also create new job opportunities with better terms. The design and coordination phase become more complex, increasing the need of qualified and knowledgeable labour. From a societal point of view, this contributes to the economic welfare and prosperity. Moreover, as stated by Buckley (2014), for the last three decades, an increasingly growth of subcontracting practises in combination with increased competitions from multinational companies has created a market for insecure employments with low wages and poor working conditions, not rarely occupied by exposed migrant workers.

Meanwhile, Hwang et al. (2018) described the situation with shortage of skilled construction workers in some places due to aging workforce, while Navaratnam et al. (2022) emphasized the possibility of long-term employments on factories instead of contractual temporary employments at construction sites located in different geographical areas. Since industrialization of construction is not merely associated with negative side effects, it still entails scientific and societal value, making research about this tolerable, as long as implementation of industrialization will be done in a humble and humane way.

1.7 Structure of the report

This introductory chapter is followed by Chapter 2, where the research method is introduced and accounted for. Chapter 3 covers the basic concept of industrialization of construction and the fundamental aspect of modular construction. Moreover, the theoretical perspectives used in this report are presented and elaborated. These theoretical perspectives function as lenses, from which information are processed through, and used for Chapter 4 to 6. Chapter 4 is where the theoretical findings, from various scientific sources, are presented. The results from the empirical research is located in Chapter 5. Further, the theoretical findings are compared and analysed in comparison with the empirical research in Chapter 6. The result is then dissected, and additional ideas are discussed to add nuance to the findings in Chapter 7, giving a wider and more holistic picture of the whole concept of modular construction. Lastly, Chapter 8 concludes this report by summarizing the discoveries of this research.

2 Methodology

The research methods are introduced and accounted for in this chapter. As Bryman and Bell (2011) stated, methods are not neutral tools, thus, a transparent description is needed in order to assess and validate a research and its results.

2.1 Research approach

The adopted research strategy for this report was a qualitative research. According to Bryman and Bell (2011) a qualitative research is focusing on words instead of numbers when collecting and analysing data. How individuals interpret their social world is of interest in a qualitative research (Bryman & Bell, 2011).

There are different approaches to use for a qualitative research. Bryman and Bell (2011) mentioned the *inductive* research strategy as collecting data to build a theory while a *deductive* approach is when research is steered by theories. Further, Awuzie and McDermott (2017) described the *abductive* approach as a back and forth motion between data and theory to develop existing or new theories, a mix of both the inductive and deductive approaches. This report is a product of the abductive approach where the process of collecting and analysing theories and research data has been a back and forth process.

2.2 Literature review

Webster and Watson (2002) emphasized that the process of identifying relevant literature as a fundamental element of an academic project, with an effective literature review a basis for theory and knowledge development to be achieved. Further, Webster and Watson (2002) mentioned that a good review is not limited to a small number of journals nor any geographical region.

MacLure (2005) depicted a systematic literature review as a procedure to filter relevant literature and discard inapplicable literature without reading them. After limiting the numbers of relevant literature through, for example, key words, trustworthiness and screening of abstracts or titles, in-depth reviews are made.

Greenhalgh and Peacock (2005) highlighted that personal knowledge, either by own existing knowledge or from personal contacts and networks, could provide useful literature. Furthermore, Greenhalgh and Peacock (2005) reported about snowballing, which involves following up references from reference lists to identify relevant literature.

The literature in this report has been identified using a systematic literature review using primarily databases indexing peer-reviewed scientific publications to ensure a certain degree of quality in the identified literature. Additionally, previously known literature with relevance to this topic has been used. The snowballing concept described by Greenhalgh and Peacock (2005) was also used to further identify relevant literature from useful sources. The geographical origin of a source has not been a deciding factor whether a literature was deemed relevant or not, the content and relevance has instead been the decisive attributes.

2.3 Empirical research

All the data in Chapter 5 is from the interviews with the five interviewees. Four interviews were conducted through video conferencing and one interview by written communication. Due to prevailing regulations, the interviewees are anonymized and this was announced to all the interviewees in conjunction with the interviews.

An interview with one of the interviewees, in this report anonymized with the nickname the *client interviewee* and will be further described in Section 5.1, was conducted through written communication, more specifically by e-mail. This was due to the busy schedule of the interviewee. Opdenakker (2006) classified e-mail as an asynchronous communication in both place and time, this limits the disturbance for the interviewee, as answers to questions are not dependent on time and place. This form of interview also allows the interviewee to have more time to reflect on the questions. Nonetheless, spontaneous answers and lack of social clues are difficult to acquire through this form of interview (Opdenakker, 2006).

Four of the interviews were conducted through four video conferencing and lasted between 30 to 60 minutes. Both video and audio were used for the interviews and the only participants were the author of this report and the interviewee. The interviewees were informed about this research and about their anonymity in this report. All the interviews were recorded with approval from the interviewee and used to transcribe for further analysis. Lobe and Morgan (2021) categorized the benefits with video conferencing interviews as a way to interview participants which are difficult to reach or geographically located far away. Saarijärvi and Bratt (2021) described video conferencing interviews as the most similar to face-to-face interviews and depending on the camera of the interviewees, they can be observed partially or fully. For this research it was partially, only facial expressions and hand movements could be observed.

Bryman and Bell (2011) characterized semi-structured interviews as a research method using an interview guide with questions of topics which are of interest. However, the interviewer is not limited by this interview guide and can freely ask follow-up questions depending on what answers they get from the interviewee. Thus, Bryman and Bell (2011) called this a flexible interview process. Since a qualitative approach was selected for this research, the importance of the individual's interpretation of the social world is of essence. Therefore, the semi-structured interview method has been selected to be able to clarify and further learn more about their interpretations through additional questions.

The interviewees were selected due to their expertise and because they represent different aspects of industrialized construction. Where one represents a more traditional construction company, while two represent more industrialized construction companies in various degree. One interviewee was involved in an early innovative modular construction project and one interviewee represent the client's view.

2.4 Figures and tables

Figure 1, 7, 8 and 10 were retrieved from different sources which are either licenced for educational use or creative commons licenced. The rest of the figures and tables in this report were created by the author with information and data adopted from various sources, as stated in the figure text.

3 Theoretical framework

Industrialization of construction and modular construction is described in this chapter, with a brief description of the concept and history of industrialized construction. This section is placed here as an introduction to the topic of modular construction before the theoretical perspectives used in Chapter 4 to 6, lean and change management, are presented and clarified.

3.1 The concept of modular construction

Constructing buildings with modules involve the implementation of various processes that alone or in combination can be considered as industrialization of construction, examples of these processes include use of mechanical tools, computerized steering systems, standardization of products, modularization and mass production (Attouri et al., 2022). Moreover, Rashidi and Ibrahim (2017) mentioned the process of manufacturing building components in a controlled environment off-site, with different level of mechanization, automation and even robotization. Thus, Attouri et al. (2022) stated that there is no clear definition on the principle of industrialized construction and what constitutes industrial construction varies depending on the context of a study and between different countries. Furthermore, different terminologies are used interchangeable in literatures to describe the same phenomena of industrializing construction. The terms modular construction, industrialized construction, modern method of construction, off-site production, off-site manufacturing and prefabricated housing can all be seen describing the process of industrializing construction (Attouri et al., 2022). This report uses the term modular construction to emphasize the use of modularization and the following subchapters will describe the processes included in the definition of modular construction for this report.

3.1.1 The history of industrializing construction

According to Goh and Loosemore (2017) the idea of industrializing construction is not a new or recently adopted concept. Abdelmageed and Zayed (2020) further specified that prefabrications can be dated back to the 17th century, where prefabricated components were made in England and shipped to the United States to be built. Several other examples of off-site construction can be traced throughout the 19th century, where prefabricated building components were manufactured and shipped to different colonies for construction (Taylor, 2010). However, prefabricated buildings were not only limited to residential housing nor primitive buildings, with the building *Crystal Palace*, illustrated in Figure 1, as a fine example of that (Abdelmageed & Zayed, 2020). *Crystal Palace* was completed in year 1851, prior the Exhibition of All Nation held in London (Addis, 2006). According to Addis (2006) it was one of the most iconic building representing the 19th century architecture and a symbol for the transition from traditional construction to a more modern approach. While the building was indeed a remarkable achievement, with a construction time of only 190 days, it was actually not utterly innovative. Addis (2006) stated that *Crystal Palace* was built using, at that time, proven technique, design and materials. Indicating that the development and usage of a more industrialized approach up until then was undeniably occurring.

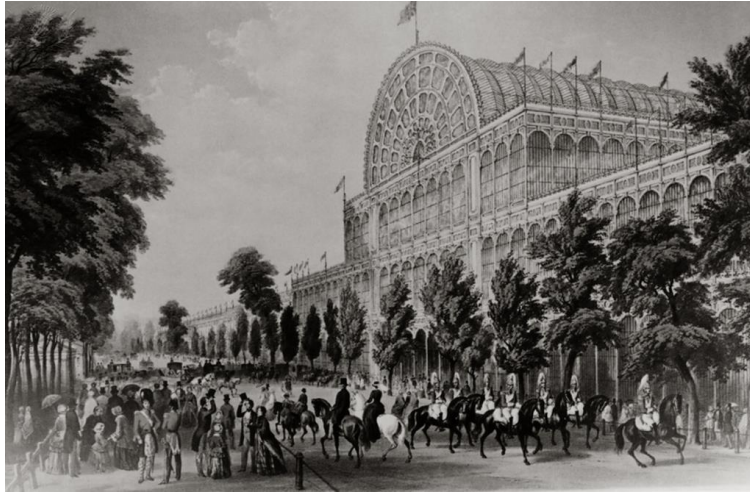


Figure 1 A portrait of the prefabricated building Crystal Palace in year 1851. Retrieved from Britannica ImageQuest (n.d.a).

Industrialized and off-site construction were periodically used for various projects after the completion of Crystal Palace, and Taylor (2020) mentioned that it was not until the 1920s that off-site manufactured building components usage gained a substantial growth. Explained partly by housing shortage and increased prices for traditional buildings. Nevertheless, these projects proved to be problematic with corrosion and increased costs among other things. Gradually, the construction sector moved back to using traditional construction. However, Taylor (2010) described the re-emergence of prefabrication after the Second World War but also how, historically, the usage of industrialized processes rises with increased housing demands.

The industrialization techniques continued to evolve and during the 1990s, modular construction was used for residential buildings, prisons and hotels (Taylor, 2010). Modules were also being used to build commercial buildings and luxury residential. Nowadays, residential buildings with over 40 storeys, rising over 140 meters have been built, consisting of 3D-volumetric modules (Abdelmageed & Zayed, 2020).

3.1.2 Different level of industrialization

Roughly speaking, construction can be conducted through different construction methods which represent various degree of off-site manufacturing, Goh and Loosemore (2017) described different levels of industrialization, demonstrated by Figure 2. In the model by Goh and Loosemore (2007) *traditional building* represents the lowest level, consisting of handcrafted on-site manufacturing but also installation of prefabricated components including pipes, windows and doors. Level 1 is *on-site prefabrication*, which comprises of on-site elements assembly in a dedicated area, located closely to the construction site before moving to the correct position for installation. Level 2, the *off-site prefabrication*, reminds a lot of on-site prefabrication with the difference that the prefabrication phase is accomplished in a remote area before transported to construction site. *Pods* represent level 3 and involves off-site manufactured units which are pre-assembled, ready to be connected to other building components on-site. The highest level of industrialization is obtained by using *complete modular*, namely, off-site manufactured complete units where these together can form the structure of a finished building.

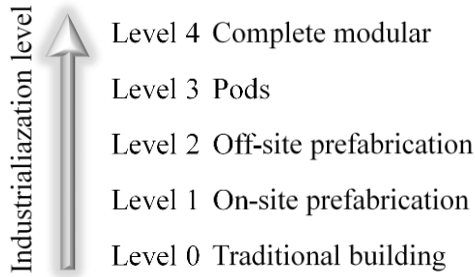


Figure 2 Industrialization level of different construction methods. Adapted from Goh and Loosemore (2017).

3.1.3 The modular construction process

Modular construction, in this report, assume construction through off-site produced 2D-panels and 3D-volumetric modules, thus, equalling the industrialization level 2 and higher, described in Section 3.1.2. In accordance with Goodier and Gibb (2007), the modular construction process consists of manufacturing of 2D building elements and 3D-volumetric modules in off-site factories. Thereafter, these building blocks are transported to the final destination for assembly (Ferdous et al., 2019; Wasim et al., 2022). Figure 3 shows the flow of materials through the modular construction process. The implementation of modular construction can be achieved in many different ways, the same can be said about manufacturing of components and coordination of the project (Olawumi et al., 2022). This will be further described in Chapter 4.

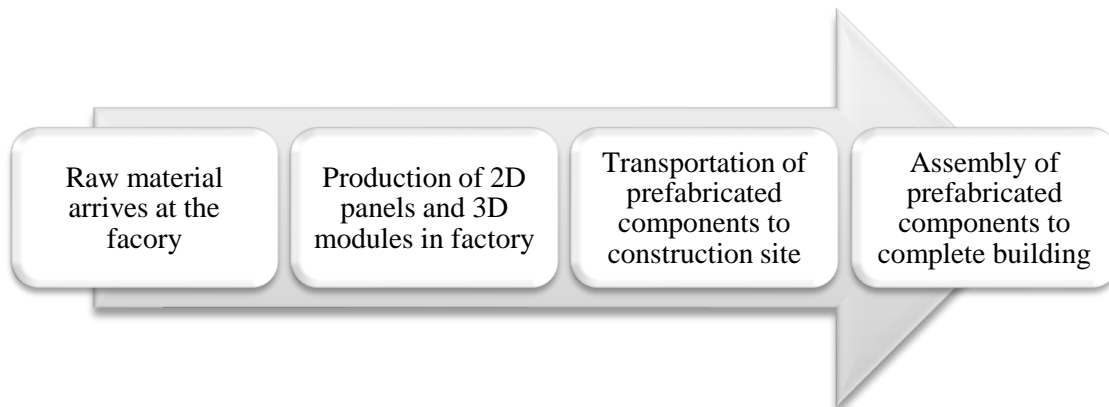


Figure 3 An illustration of the material flow from raw material to a finished building. Adapted from Ferdous et al. (2019).

3.2 Theoretical perspectives

Lo (2016) stated that research papers need to address the used theoretical perspectives, as these will frame and guide the study. Further, Lo (2016) elaborated that a theoretical perspective functions as a lens, through which phenomena is studied. The same phenomenon studied by different lenses yields different interpretations and

results, hence, theoretical perspectives functions as a delimitation and limits the way on which the phenomena is viewed. Lo (2016) concluded that a combination of lenses would give a better understanding of the investigated phenomenon, describing a metaphor where multiple lenses in combination would create a pair of glasses giving the user a good vision both at close and long distances. Hence, this report adopts two theoretical perspectives, namely, lean and change management. The combination of these two lenses are deemed to ease the identification of improved practises regarding modular construction while remaining possible to implement.

3.2.1 Lean

Compared to the manufacturing industry, the construction sector has not gained the same kind of productivity development (Yu et al., 2013). For instance, Winch (2003) described about the perceived superior innovation rate of the automobile industry compared to the construction sector. Adopting lean construction is a way to translate the success of the automobile industry to construction, as lean is influenced by methods developed by the car manufacturer Toyota (Gao & Low, 2014). The work by Koskela (1992) lay the foundation to what became known as lean construction, an adoption of the lean concept for construction (Yu et al., 2013; Pan & Pan, 2022). Koskela (2000) elaborated this concept to consider the construction process as a procedure affected by the principle of transformation, flow and value generation.

Koskela (2000) described the transformation models by considering production as a process of transformation, where various forms of inputs transform to desired outputs through the production process, represented in Figure 4. These inputs are not limited to raw materials but also includes, for instance, labour and machineries.



Figure 4 The transformation model where inputs are transformed to outputs through a production process. Adapted from Koskela (2000).

Koskela (2000) further characterized the flow concept, which emerge as a critique against the transformation model. This critique based its assumptions on the lack of consideration for important events occurring between different transformation procedure in the production process. For example, inspections and transfer of materials which is not directly connected to the transformation process but required in order for the transformation process to be accomplished. The flow concept captures this critique by introducing time as a factor in production. Consequently, the flow of materials is improved if non-transformational time-wasting is reduced, including time consumption due to transfers, delays and variabilities. The idea of just-in-time, Toyota production system and mass production by Ford are examples of practices based on the flow concept.

For value generation, Koskela (2000) defined it as another critique against the transformation model. Here the critique is targeted at the lack of customers' perspective, underlining the focus on internal production instead on the needs of customers. In fact, Koskela (2000) emphasized the essential difference between these two points of view. Since the value generation concept focuses on control of the transformation and flow, but for the sake of customers and not for improving the physical production process. The control consists of passing on the requirements and expectations from customers to the internal product design and production phase, to deliver value for customers. Essentially, adapting the production procedure to fulfil or exceed customers' demands.

Koskela (2000) stated that the transformation, flow and value generation concepts, despite its differences, should not be viewed as conflicting theories but rather as complementary, as each of them on their own is not comprehensive enough. A combination of them results in consideration regarding value-adding transformation, non-value-adding activities and customers' satisfaction. The challenge is to reach a balance between these three aspects, something that might be different from case to case.

Since the groundwork development by Koskela (1992) and Koskela (2000), lean construction has evolved and turned into a new discipline, although not without debate on its implication (Pan & Pan, 2022). Kifokeris (2021) described the lack of a distinct and general definition of the concept lean construction. According to Pan and Pan (2022) a distinction can be traced to all the different interpretations of lean construction, as they all in some way embrace the fundamental principles of lean, namely, minimizing waste and maximizing value. Value in this sense does not only imply production value but also value for customers, in accordance with the value generation concept described by Koskela (2000). Tzortzopoulos et al. (2020) mentioned that lean construction has mostly been focusing on reducing waste in construction projects but that lean design, which consider design as a production phase, is the main source of value for clients. However, lean implementation for the design remains modest, indicating that not all three aspects of lean has had equally attention.

Pan and Pan (2022) acknowledged a trend with the integration of lean construction to address emerging topics and practises regarding the construction sector such as sustainability, prefabrication and modular construction. Goh and Goh (2019) argued that the principle of lean construction has the possibility to increase the efficiency of modular construction and thereby facilitate its implementation, further, the similar nature of goals for both the concepts is highlighted. Likewise, Yang et al. (2022) agreed on the similarities between the concept of lean and modular construction, including promotion of just-in-time deliveries. Goh and Goh (2019) added that there were plenty of real cases where successful lean implementation resulted in productivity improvements for modular construction related businesses, such as factories producing modules. It is, therefore, not a coincidence that this report has adopted the lean perspective to study the principles of modular construction. Practices that in theory constitutes as lean, should with this reasoning also be optimal for the implementation of modular construction. However, the benefits with lean principles remain worthless if it cannot be implemented, which could prove to be more difficult

than anticipated despite all the advantages lean implementation implies (Demirkesen et al., 2019).

3.2.2 Change management

Nordin et al. (2012) illuminated the difficulties with implementing lean practices, even for the manufacturing sector, despite its many successful cases. Further, Nordin et al. (2012) described the transition as a process full of challenges and often condemned to fail at some point during the implementation. AlManei et al. (2018) argued that the failure of various roadmaps and frameworks to implement lean was due to the lack of consideration on the human factor and the complexity this entails. Moreover, Furman and Kuczynska-Chalada (2016) emphasized about the importance of the employees and their involvement for a successful implementation. In line with this, Höök and Stehn (2008) reasoned about the need of a fundamental change in the organizational culture to a lean culture, thus, the human factor should not be neglected. Nordin et al. (2012) claimed the success of lean implementation was dependent not only on manufacturing and technical aspects but also cultural, often with major structural and strategic alterations to an organization, underlining the need for change management. Consequently, Shah and Ward (2003) recognized the importance of organizational characteristics and highlighted that not all organizations can implement changes through the same template.

Change management is a broad definition of continuously performing tasks to estimate and analyse change factors, organizing countermeasures to support decision making but also monitoring progression to make correct measurements (Cho et al., 2015). Moreover, it has been described as a structured process to guide the human side of change to reach a predetermined outcome (Xiong et al., 2016). Likewise, change management has been associated with preparing affected people to accept the change (Harrington & Voehl, 2015). In addition, it can be considered as a body of knowledge on how to adopt organizational changes (Abrantes & Figueiredo, 2013). Regardless, there are many approaches and methodologies developed to reduce the difficulties of implementing change (Harrington & Voehl, 2015). It is notable, however, that there is no best practise to manage change due to the complexity of organizations, rather it is about finding a better way forward (Errida et al., 2018).

Harrington and Voehl (2015) stated that there are various change management models available, some of the more popular models will be described here to exemplify the underlining concept. According to Galli (2018) *Kurt Lewin's change management model* is one of the more widespread models. The idea with this change management model is to abandon current behaviour before adopting new behaviours and, thus, successfully make the change (By, 2005). This is done by three steps illustrated by Figure 5, specifically, to *unfreeze* the current state, followed by making the *change* and ending with *refreeze* to keep the desired state. Bamford and Forrester (2003) described this model as a planned change model which considers breaking down old behaviour, structure and culture before new methods can be implemented.



Figure 5 Kurt Lewin's three steps change management model. Adopted from Galli (2018).

Galli (2018) described *Kotter's 8 step change model* as another commonly used change management model, these 8 steps can be seen in Figure 6. The first step after discovering the need for a change is to create a sense of urgency in the organization to increase awareness of the necessity to change. Step two is to create a group of leaders willing to make the change happen. Step three involves creating a clear vision or roadmap to establish an understanding for the transformation. Step four encompasses the communication of the vision or roadmap created in step three, and this step is crucial to reduce resistance which could rise if there is no understanding from the employees why the change is necessary. Step five includes supporting employees and allowing them to try new approaches and ideas in order to remove any obstacles interfering the change vision. Step six consists of creating progress. Short-term wins are a way to establish the importance with the change and the change process. Step seven entails to continue the additional change implementation needed to reach the vision, this step is important since the progress made after step six risks resulting in participants falling back to old habits. Finally, the last step is to institutionalize the change into the organizational culture to make it a part of the routine behaviour.

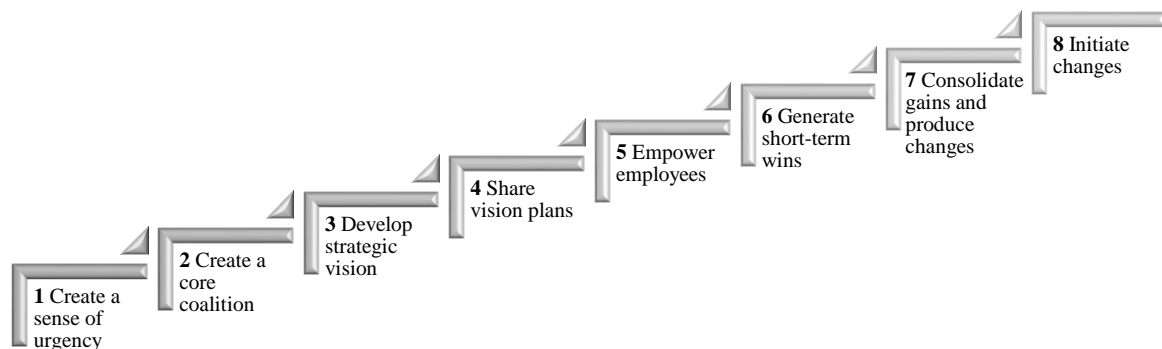


Figure 6 Kotter's 8 step change model. Adopted from Galli (2018).

Bamford and Forrester (2003) mentioned the contrast to the planned change models, such as Kurt Lewin's three steps change model and Kotter's 8 step change model, which is the phenomenon of emergent changes. Bamford and Forrester (2003) further described emergent changes as a critique against the assumption of managers being able to plan for needed changes. As the environment in which the organization operates in is uncertain, this creates changes in the organization which occurs at a quick and complex way making it difficult for management to control. Instead of change plans moving from top to bottom, the concept of emergent changes advocates changes moving from bottom to top. Therefore, the manager's role is to facilitate changes rather than creating a step by step roadmap (Bamford & Forrester, 2003).

Indeed, there are many different approaches to consider the change process (Galli, 2018). Galli (2018) argued that finding the most effective process or model for an organization to change is almost a random process, due to the diverse characteristics of project teams in an organization. Change management could, therefore, be simplified to be about transforming from the current state to a desired state (Galli, 2018), with the task of management to facilitate changes and steer the progress towards a certain direction similar with the concept of emergent changes described by Bamford and Forrester (2003).

4 Literature Review

In this chapter, the findings from the literature review are presented. The chapter begins with a clarification of modularity and modular construction, where buildings can be constructed by smaller units. Thereafter, the design coordination through BIM is explored, followed by the manufacturing of the prefabricated components. The last section in this chapter described the benefits and drawbacks with different form of organizational structure.

4.1 Modularity for construction

Voordijk et al. (2006) described the concept of modularity as building a complex product from smaller standard parts, providing a flexibility to create products which customers need and still using standardized components. Likewise, Bertelsen (2005) characterized it as value through individually designed product with the efficiency of mass production. Additionally, Du et al. (2019) depicted a module as an independent but essential part of the product it forms, with standardized interfaces allowing them to be combined into a full system.

Bertelsen (2005) explained how other sectors transformed into a modularity mindset with the IT company IBM as an example. Computer manufacturing was, before IBM revolutionized the production process, a matter of a closed system where products were designed and built after the requirements of customers. This closed system meant that computers needed to be considered and design as a whole system each time. IBM changed the concept by using an approach which turned the computer system into different units, such as processor, storage and disk drives. All the different units could then be designed and manufactured independently as long as they produced the task needed by the system. Production of computers then turned into a process of selecting units which correspond to the requirements of customers, resulting in a higher flexibility. Similarly, modular construction could be regarded as breaking down the production of a building into smaller parts, focusing on the functions of every parts instead of considering the building in the traditional way, where a system composes of the structure, envelope, piping, electrical systems and so forth (Bertelsen, 2005). Section 4.1.1 and 4.1.2 further describe the idea with these smaller components.

4.1.1 2D-panels

The purpose with 2D-panels is to produce individual components off-site, including for example walls, facade, beams, floors and frames (Luo et al., 2021). These components can reduce on-site activities, for instance, walls could have pre-cut openings for doors and windows, thereby reducing another task needed on-site (Zhao & Riffat, 2007). With these components, the construction on-site turns into a series of assembly operations to complete the building (Lu & Liska, 2008). 2D-panelised systems can beside panels also include different forms of trays, cassettes or flat packs (Dave et al., 2017). An example of 2D-panels is portrayed in Figure 7.



Figure 7 An example of 2D-panels, specifically, timber panels with foam insulator. Retrieved from Britannica ImageQuest (n.d.b).

Regarding raw materials, prefabricated 2D-elements can be made of various materials, as described by Luo et al. (2021). Luo et al. (2021) further mentioned that concrete is well-researched when it comes to material for prefabrication and has in many ways become the main source for prefabricated constructions. Nevertheless, steel and wood remain important materials in practise due to sustainability reasons. Additionally, prefabricated elements can be made of mixed materials, with different forms of composite materials, such as steel reinforced concrete and steel-timber structures. Walls can also be supplemented with insulating material of different materials (Luo et al., 2021).

Zhao and Riffat (2007) mentioned the benefits with 2D-panels as cost savings through mass production, reduced labour costs on-site, reduced waste, high-quality components and increased productivity. Nazir et al. (2021) also pointed out that the reduction of on-site tasks potentially could reduce on-site accidents.

4.1.2 3D-volumetric modules

Yuan et al. (2021) characterized the construction process with modules as an off-site production of modules, followed by transportation to construction site and then assembly to a finished building. These buildings are made up by several 3D-volumetric modules and every module can have different degree of pre-assembled installations, such as plumbing and electrical installations (Lu & Liska, 2008). Figure 8 exemplifies how 3D-volumetric modules can look like. Hwang et al. (2018) described the modules as having walls, ceilings and floors manufactured in factories and, hence, relocating up to 85 to 90 percent of the project work off-site. The modules can be designed to be placed directly on top of each other without extra support (Lacey et al., 2018). However, accumulated damages due to repeated loads from multiple transport cycles and progressive collapse occurring from local damages resulting in overload on structural elements are potential dangers. Moreover, Wasim et al. (2022) mentioned about the structural stress on 3D-volumetric modules which occur during transportation and lifting, creating an extra load that needs to be designed for.



Figure 8 An example of 3D-volumetric modules. These modules have floors, ceilings and four walls prefabricated. Retrieved from Province of British Columbia (2011).

Lacey et al. (2018) stated that modules can be classified as timber, precast concrete or steel depending on its primary construction material. Lacey et al. (2018) further described the advantages and disadvantages with the different materials. Timber is a sustainable material and easy to fabricate but has weaker fire resistance and durability. Precast concrete has better fire resistance but also better acoustic insulation, thermal and vibration performance. However, it is heavy and there is a risk that cracks occur in corners. Steel is lightweight, have high strength and is easy to transport but it risks corroding and may need supplementary reinforcement when there are openings for doors and windows in the walls. Aside from these three materials, composite materials can also be used and examples of these are glass fiber reinforced cement, steel-timber composite and fiber reinforced polymers (Lacey et al., 2018).

According to Zhao and Riffat (2007) modules produced in factories can be mass produced which reduce costs. Further, Hwang et al. (2018) underlined that 3D-volumetric modules give the possibility to proceed tasks simultaneously and thereby reduce the construction time significantly compared to traditional construction, where some activities cannot proceed before others have ended. The manufacturing of modules in factory environment also creates a better and safer working environment for workers, by reducing the number of high-risk tasks on-site as concluded by Ahn et al. (2020). Additionally, the need of labour and equipment on-site reduces when using modules (Hwang et al., 2018). Moreover, transferring the production off-site reduces delays and waste due to vandalism, theft and weather conditions (Navaratnam et al., 2022). Jaillon and Poon (2010) also mentioned the flexibility to over time alter the module configurations to customize the building according to user preferences but also the possibility to demount the modules for repair or reuse in other locations.

4.1.3 2D-panels and 3D-volumetric modules composition

From a transformation and flow aspect, using as many 3D-volumetric modules as possible would yield the most benefit concerning waste reduction and productivity.

However, as described in Section 3.2.1 Koskela (2000) emphasized a balance between the three principles of lean, where one of them consider values for customers. Hence, 2D-panels could be used as a complement in projects which requires specific demands which cannot be solved by only using 3D-volumetric modules. A hybrid building consisting of 2D and 3D elements would with this argumentation still be considered as lean construction, albeit with a reduce industrialization degree. Nonetheless, Bertelsen (2005) argued that modularity requires a different mindset compared to traditional construction, as modularity emphasizes function instead of division by trade. Subsequently, 2D-panels can be experienced as a less radical change in the construction process compared to 3D-volumetric modules for organizations which largely use traditional construction. As Bertelsen (2005) stated, 3D-volumetric modules are an output of several trades while Luo et al. (2021) mentioned that 2D-panels could be as simple as plain prefabricated walls. Therefore, having the employees' agreement on implementing 2D-panels might be easier compared to using 3D-volumetric modules which requires a higher degree of alteration in the mindset.

4.1.4 Challenges with modular construction

As described in Section 4.1.1 and 4.1.2, there are many benefits with using modular construction, yet its utilization in the construction sector remain limited (Hosseini et al., 2018). Evidently, there are challenges and barriers complex enough to hinder a widespread adoption (Navaratnam et al., 2022). Cost-related reasons can be seen reported in many different sources (Chiang et al., 2006; Rahman, 2014; Navaratnam et al., 2022). These costs derive from investments in factories and machineries (Rahman, 2014). In addition, costs for the ground on which the factory is placed on, which for some places in the world could be difficult and expensive to obtain (Chiang et al., 2006). Without a steady demand for these products, it could also be difficult to justify the investments needed (Liu et al., 2022).

According to Navaratnam et al. (2022) knowledge deficiency could act as a barrier. The competence needed for on-site and off-site production differ, with off-site production demanding a more machine-oriented mindset among workers (Chiang et al., 2006). Navaratnam et al. (2022) further described the lack of experience as a barrier where, for some places in the world, the market for modular construction is very limited, resulting in a small group of practitioners with experience of working in this kind of projects. Combined with less focus on industrialized construction on higher education studies, resulting in a lack of necessary competence. Furthermore, high-profile failures in the past results in a suspicion against modular constructed buildings (Navaratnam et al., 2022). As Chen et al. (2010) stated, decisions to use prefabricated components are related to preferences and familiarity with the technology, thus, the lack of experience, knowledge and negative experience could result in a high threshold for organizations to cross.

The process of modular construction is rather complex, for instance, the coordination between on-site demand and off-site production needs to be addressed to produce a productivity growth (Arashpour et al., 2016). Moreover, Rahman (2014) described the lack of standards for the design phase but also the need of frequent communication between different disciplines. Further, Rahman (2014) mentioned the necessity to have the building design fixed at an early stage to produce components that fit together, making modular construction less flexible than traditional construction for

late design change. Blismas et al. (2005) also stated that some architectural designs are difficult to construct through modular construction.

4.2 Design coordination

As described in Section 4.1.4, the coordination between different disciplines could be difficult and complex. Navaratnam et al. (2022) claimed that tools such as *Building Information Modelling*, or henceforward refer as BIM in this report, could facilitate and improve the collaboration between architect, engineers and managers. With BIM, a 3D visualization can be achieved and a higher creativity can be obtained, but also the ability to have useful information included in the model. This section will address the concept of BIM and how it could be used as a vital tool for the implementation and utilization of modular construction.

4.2.1 The history of BIM

According to Volk et al. (2014) 3D modelling started to develop as a technology in the 1970s and was based on computer-aided design, or more known as CAD. While the basics of BIM were gradually implemented in many sectors it was not until early 2000s that BIM was used for pilot construction projects (Volk et al., 2014). Initially, BIM was used as a supporting tool for architects and engineers when creating the building design. BIM as a tool, however, developed and research focused on the role BIM could have for design and planning, clash detection, quantification, cost and data management but also for visualization (Volk et al., 2014). The potential of BIM was further recognized and its role for the construction industry was expanded. From only being developed for preplanning and design of the building, research began to investigate its use as a tool for maintenance, refurbishment, deconstruction and for end-of-life considerations.

Azhar (2011) described BIM as not only a software for simulation of a construction project in a virtual environment but should instead be considered as a process and software. Azhar (2011) further argued that BIM usage is not limited to implementation of a software nor as a 3D modelling tool only. Instead, it should also be regarded as a virtual process that can combine all disciplines, aspects and systems into one model, providing benefits which all team members can profit from. This is a process which Azhar (2011) claimed meant remarkable changes for the project delivery process and for the workflow.

4.2.2 The role of BIM for modular construction

The usage of BIM is definitely not restricted to be used with modular construction only, Bhattacharya and Mathur (2022) claimed that BIM alone has the potential to function as an instrument to apply lean principles for the construction sector. Value through different dimensions can be delivered by BIM, including dimensions such as time, cost, sustainability, facilities management but also health and safety (Bhattacharya & Mathur, 2022). Nevertheless, Yin et al. (2019) argued that the two interrelated paradigms of BIM and modular construction could together significantly improve the performance in the construction industry. Furthermore, Abanda et al. (2017) emphasized that BIM can offer even more benefits for modular construction compared to traditional construction, due to the factory-based nature of modular

construction. According to Abanda et al. (2017) off-site prefabrication requires effective information exchange between the supply chains to be successful, something that BIM can offer, with its information management capability. Hwang et al. (2018) also mentioned the improvements BIM might yield for the coordination of different disciplines through better interaction between engineers and contractors but also by providing a better understanding of the geometry of modules prior manufacturing.

Ramaji et al. (2017) stated that modular construction projects do not necessarily need to be considered as project-based but could be regarded as having a more product-based nature. This would give the possibility to implement concepts used for industrial engineering on modular construction. One of these concepts is to link design, manufacturing and construction. Products are then broken down into different units of components which are designed in a collaborative multidisciplinary way. Cao et al. (2022) reasoned that these units of components could be used as a standardized module library for multi-project utilization. Standardized 3D-volumetric modules can be developed as a BIM file, containing data to make 3D visualization possible and information for analysis but also for making predictions. Included information in these files can be the configuration of the modules, materials, size but also alternative suppliers and manufacturers. This module library can be reused for many different projects and, thus, reduce the need to redesign components and building design for every project. However, Cao et al. (2022) emphasized the risk of having too many units in the module library and compared it with the case of the toy production company Lego Group, which in the early 2000s had over 12 000 different Lego pieces causing the company severe difficulties to manage them all.

4.2.3 The challenges with BIM

According to BorjeGhaleh and Sardroud (2016) the exact definition of BIM and what needs to be included is not universally defined and different views of what can be considered as BIM exist nowadays. This complicates the implementation process somewhat and the complexity does not decline with a reported number of over 150 BIM software available (Abanda et al., 2017). Moreover, Volk et al. (2014) described the issues regarding incompatible data when using different software and the challenge in data exchange this imply. Although, universal data structure has been developed and improved, BIM as a technology also has developed with management and synchronization of data still proving to be a challenge (Volk et al., 2014).

The challenges with the implementation of BIM is not only limited to technical obstacles but also includes the need of qualified competence, the willingness to cooperate and cultural differences (Volk et al., 2014). Furthermore, Volk et al. (2014) mentioned that the data in a BIM model and its accuracy is dependent on the ability of constantly providing it with updated and correct data, otherwise the trustworthiness of a BIM model will disappear and the readiness to use its data might decline. Unfortunately, the data in a BIM model is not always processed directly in the model, extraction of data can be done and processed externally, thereby increasing the risk of inaccurate data (Volk et al., 2014).

Beside the challenges general BIM implementation entails, Ramaji et al. (2017) also stated some additional challenges concerning BIM implementation for modular construction. Information exchange and consideration for activities related to modular

construction needs to be addressed, this includes manufacturing, transportation, installation and intentions with the modules after its service life, such as reuse or decomposition.

4.3 Manufacturing of components

Many of the benefits with modular construction described in Section 4.1.1 and Section 4.1.2 is valid for both manual production, using manual labour, and for automated production which consists of production using various degree of automated machineries. This section describes the production phase of off-site prefabricated components.

4.3.1 Manual production

Manual production for off-site modular components, such as 2D-panels and 3D-volumetric modules, includes assembly, installation and production using traditional methods but could also imply to using different kinds of tools to reduce the dependency of workers (Rashidi & Ibrahim, 2017). The available tools in the factories can provide workers with a better ergonomic and, hence, improve productivity (Olawumi et al., 2022). Nonetheless, the factory-controlled environment also increases productivity by eliminating the negative effect of extreme weather conditions (Santa Cruz Astorqui et al., 2022). Typically, summer conditions could derive in reduce performance and productivity due to the heat in the work environment. Similarly, winter conditions affect workers' performance by reduced mobility as a consequence of body and muscle cooling but also from the weight of their protective clothing.

Even though manual production of prefabricated components is dependent on labour from workers, the production is still carried out in factories, providing it the potential to have a better utilization of manufacturing principles, such as just-in-time (Oral et al., 2003). Simultaneously, the manual labour procedure provides a flexibility regarding technological requirements with Johnsson and Meiling (2009) reported about factory workers using printed drawings in the manufacturing process.

4.3.2 Automated production

Rashidi and Ibrahim (2017) defined automation as a process of replacing workers with machineries, while robotization as replacing even more workers with machineries capable of complex and diverse tasks. Han et al. (2020) summarized the automated process by starting with transferring the desired component model to a machine through software, in which the machinery will perform its task and the end-product received from the machines might need some additional manual work.

García de Soto et al. (2018) depicted the wish to replace manual labour with robots as an old phenomenon, explored since the early 80s. Although, efforts were made to substitute manual labour on-site, this is still a rather limited occurrence. Instead, off-site production in factories turned out to exercise this phenomenon in a more common manner. García de Soto et al. (2018) further described the automated production as a combination between computational design and automated construction process. The automated process can involve the removal of material using chemicals, electrical

milling or mechanical milling. Materials can also be formed or reshaped using mechanical forces, heat or through restricting forms. Furthermore, production can consist of assembly or gluing of different layers to produce a solid element. Different form of machineries can be used to achieve the automated process, including laser cutters or computer numerical control milling (García de Soto et al., 2018).

According to Pan et al. (2021) 3D printing, as a technology, is also emerging and potentially can change the production radically. Han et al. (2020) explained the concept of 3D printing as adding materials in layers upon layers, a method known as additive manufacturing. Advantages with 3D printing includes reduce labour requirements and time for production but may also provide a higher architectural freedom (Pan et al., 2021). Nonetheless, 3D printing remains a complex procedure with dependency to different kinds of technical solutions such as BIM models and printing systems (Pan et al., 2021). Thus, requiring a more radical change than manual production.

4.3.3 Factory location

Rahman (2014) emphasized the logistical challenges with 3D-volumetric modules. Since these can be rather large and heavy, the transportation can be expensive, especially if the factory is located far away from the construction site. Hence, placement of factories can impact the performance of modular construction.

Selecting a location to place a factory for production of prefabricated building components is a complex decision with many factors to take into consideration (Zhu et al., 2018). The location can have a direct impact on the operation cost but also for the competence availability (Zhu et al., 2018). Aytekin (2018) described the most optimal location for a factory to be at a place where services can be created at a minimum cost but producing maximum profit. However, the factors affecting the location might be a subject of change and over time the location which once was optimal may no longer be. Aytekin (2018) further mentioned closeness to raw material, distance to markets and access to labour as important factors to take into consideration.

Sullivan et al. (2010) described the concept of consolidation centre, which are strategically placed near motorways or railways and functions as a buffer storage for goods. This buffer storage is for a limited period only and can reduce the number of transportations to construction sites by consolidating deliveries. Sullivan et al. (2010) further explained that a construction consolidation centre can store construction materials and deliver materials just-in-time when needed in a project. Thus, a construction consolidation centre can improve productivity and reduce environmental impact. Furthermore, Hamzeh et al. (2007) mentioned the possibility to use these construction consolidation centres for sorting, kitting but also for assembly. Consequently, there is a possibility to combine a factory for off-site production and a construction consolidation centre, increasing its utilization and reducing costs.

4.4 Organizational structure

This section explores the options companies can conduct their businesses through, as well as highlighting the benefits and drawbacks with different choices.

4.4.1 Outsourcing activities

Voordijk et al. (2006) described the concept of supply chain modularity and how tasks are accomplished within a sole organization or allocated among many. Every step of a construction process can be conducted by the company itself or outsourced to other companies. Likewise, activities within a construction phase, for example the design or manufacturing phase, can be resolved by the organization or by using external labour.

The decision of outsourcing can be simplified to be the choice of making or buying (Damanpour et al., 2020). Outsourcing is a strategic decision and aims to transfer some of the activities to external suppliers. Belcourt (2006) characterized the benefits with outsourcing as a possibility to acquire knowledge which is missing within the own company. Other benefits include cost reductions, increased quality and reduced time consumption. Belcourt (2006) further described the drawbacks as lower cost reduction than expected, but also the outsourcing of knowledge and skills to external parties which potentially could reduce the company's own value. Additionally, this knowledge and skills transfer could benefit competitors (Belcourt, 2006).

Compared to using own factories, outsourcing the manufacturing process could provide the possibility to quickly expand operation by using additional suppliers who can deliver the required prefabricated components (Lessing & Brege, 2018). Nevertheless, outsourcing also reduces the control over the manufacturing process and the knowledge over this process also diminish. Lessing and Brege (2018) emphasized that operating own factories generate knowledge which could be useful for outsourcing purposes whenever needed. Furthermore, the inexperience and lack of insight for the manufacturing phase could result in errors for on-site assembly of the prefabricated elements as described by Brege et al. (2014). Moreover, Johnsson and Meiling (2009) estimated that up to 90 percent of the construction tasks could be transferred off-site for modular construction. This would mean that outsourcing production of prefabricated components would give up to 90 percent of the control and work to external companies.

4.4.2 The business models of modular construction companies

Hall et al. (2022) depicted the occurrence of new business establishment with funding from large investment firms with the intention to exploit the benefits with digitalization and industrialization for construction. These companies use a different business model compared to the companies utilizing traditional construction.

Hall et al. (2022) further discussed about the implication with these companies and how they can affect the construction sector. For many of these companies in Silicon Valley, their market is residential housing due to the reduced complexity and repeatable nature. These smaller projects do not intrude the businesses of large traditional companies in an excessive manner. However, if these companies manage to increase their productivity and improve their technology, the possibility to be involved in more complex projects may affect the businesses of larger construction companies. Hall et al. (2022) compared this to the phenomenon of new technologies' entrance, which often occur in niche markets, small enough for large market companies to ignore. As this technology evolves, these companies can move towards

more complex parts of the market and have the possibility to offer what established large market companies cannot. Therefore, it is of interest to examine how industrialized construction companies have faced and solved the challenges with modular construction.

Hall et al. (2022) suggested that a business model describes the logic behind an organization's operations and value creation. Further, Hall et al. (2022) have identified three business models used by firms adopting the industrialized construction approach. The first business model involves the adoption of vertical integration, keeping control over product architecture and processes by using own labour with a self-owned factory. The whole process, from design to assembly, is coordinated by the company itself. This business model, however, requires substantial investments.

The second business model is based on system integration where the company develops a system to conduct modular construction in and outsources the manufacturing process (Hall et al., 2022). The idea is to create a digital platform in which long-term partners are used for the design, production and assembly phases. Outsourcing these processes reduce the resources and investment needed for the company.

The third business model includes the creation of a spinoff business line from an existing project-based construction company (Hall et al., 2022). The new business line involves the founding of a factory for off-site production of prefabricated components. This spinoff business line enables the parent company to use a more industrialized approach for their projects. However, Hall et al. (2022) underlined the need to educate and update project members to appreciate and use the possibilities provided by the factory.

5 Empirical Research

The result of the empirical research is presented in this chapter. All the information in this chapter was obtained by interviews with a total of five interviewees. The first section is an introduction of the interviewees. After that, the opportunities and challenges are presented. Followed by the design process and manufacturing of modular elements. This chapter ends with the description of three companies using different level of modular construction.

5.1 Background of the interviewees

A total of five interviews were made, an overview of the interviewees can be seen in Table 1. Three interviews were conducted with practitioners representing different organizations using various level of industrialized construction. An interview was made with an interviewee who was responsible for the construction of an innovative project and another interview involved an interviewee working in a company which function as the client in many construction projects. Although, some have been involved in many diverse projects, simplifications regarding their anonymized nicknames are used in this report and they are named after the degree of industrialization level the organization they represent generally conduct projects in.

Table 1 An overview of the interviewees.

| Nicknames of interviewees | Short description |
|---|---|
| <i>Traditional construction interviewee</i> | Working at one of Sweden's biggest construction company. The company uses prefabricated 2D-elements in their projects but virtually no 3D-modules. |
| <i>Semi-industrialized construction interviewee</i> | Employed in one of the leading modular construction companies in Sweden. Using both on-site and off-site production in their projects. |
| <i>Modular construction interviewee</i> | Works in a big Swedish corporate group that construct residential buildings mainly by modular construction. |
| <i>Innovation project interviewee</i> | Responsible for the construction of an innovative 3D-volumetric modular constructed building. |
| <i>Client interviewee</i> | Employed in one of the largest private real estate company in Sweden. This company initiates and is the client of many residential building projects. |

The *traditional construction interviewee* works at one of the biggest construction companies in Sweden. The industrialization level on projects conducted by this company usually corresponds to off-site produced simple 2D-elements and occasionally traditional construction, corresponding up to industrialization level 2

described in Section 3.1.2. Actually, this company does have an affiliated company working solely with modular construction. However, as this company represents the lowest level of industrialization among the interviewees and does not, more or less, use any 3D-volumetric modules in their projects, the interviewee is named *traditional construction interviewee*. The interviewee has almost 30 years of experience from the construction industry and has been working in this company all these years, albeit with different tasks. The interviewee was involved in a department working as a constructor and with building engineering physics related tasks for several years but currently works as the head of project leaders but also manager of installation and digital resources in a department where several forms of building are constructed, including commercial buildings, offices and residential buildings.

The *semi-industrialized construction interviewee* is employed in one of the leading modular construction companies in Sweden. The reason for the interviewee's nickname is because the company does not only use 2D-panels and 3D-volumetric modules, the company does offer and use traditional on-site construction methods to achieve the requirements of projects. When using 3D-volumetric modules, they solely use timber. The company has adopted the concept of lean and try to use an industrialized process as much as possible. The interviewee has political science as educational background and worked over 10 years with urban planning in municipalities but also development of business plans, new markets and strategies. Currently, the interviewee is the business manager of this company, whereby the interviewee has worked for over two and a half years.

The *modular construction interviewee* works at a huge Swedish corporate group selling timber-related construction materials and prefabricated timber products. Additionally, they construct and sell modular single-storey houses but also construct modular multi-storey residential buildings. Both timber 2D-panels and timber 3D-volumetric modules, produced in their own factories, are used for their different construction projects. One of the companies in this corporate group is a real estate company, consequently, this corporate group does not only construct for external clients but are in some projects involved in the whole process as a client, supplier, manufacturer and contractor. The interviewee has worked over 20 years at this company and participated in the development of the technical solutions used today for both 2D-panels and 3D-volumetric modules in this company. At the moment, the interviewee is the head of research and development department but also recently became the chief sustainability officer for the whole corporate group.

The *innovation project interviewee* was involved in an innovative project where a modular multi-storey building was built with the goal to function as a place for research and testing different innovations. While the construction has been completed some years ago, the project is still operating. Several organizations are participating in this project, including a university of technology, an organization working with innovation and knowledge transfer between different actors but also several companies active in the Swedish construction and real estate sector. The interviewee has over 20 years of experience from the Swedish construction industry and has been working as project leader and head of project leaders in a real estate company. The interviewee was responsible for the construction of this innovative building. Now the interviewee is a senior project manager for an organization which functions as an

arena for knowledge transfer between researcher, society and practitioners in the construction sector.

The *client interviewee* is working at one of the biggest private real estate company in Sweden. The company produces residential buildings, shops and offices to sell or rent out to customers. The company only uses external contractors and consultants for their construction projects, but they initiate and coordinate the projects. Projects involving modular construction are not so common in this company and they are currently only involved in one project using 3D-volumetric modules. The interviewee has worked as a site manager and project manager in a large construction company in Sweden for over 10 years. Presently, the interviewee is the head of the department for new construction and has been working in this company for over 6 years.

5.2 Opportunities with modular construction

As expected, the attitude towards modular construction is different among the interviewees. The *modular construction interviewee* had the most positive opinions on modular construction and estimated that it could reduce the costs with 10 to 15 percent.

All the interviewees agreed on the reduced construction time, modular construction could result in. The *innovation project interviewee* was impressed that it only took 10 days to put all the 3D-volumetric modules in the right place and have a finished building, a process that the *innovation project interviewee* described would take maybe a year with traditional construction. The *semi-industrialized construction interviewee* was a little bit more humble and claimed that a modular constructed building was complete after 2 weeks but with some additional on-site work left, however, this process would take over half a year with traditional construction. A benefit with the shorter on-site construction time, is the reduced traffic congestion. The *innovation project interviewee* even mentioned that roads did not have to be completely shut down, they could simply be temporary closed for short periods when there were activities that required it, particularly helpful for centrally located construction sites. The shorter on-site construction time also results in fewer disturbances for neighbours as stated by both the *modular construction interviewee* and the *innovation project interviewee*.

The *traditional construction interviewee* mentioned the standardized construction process as a benefit and the clarity this entails, to have a lead start and not start everything from the beginning in every project.

The *innovation project interviewee* described another advantage with modules through the possibility to move them to another place if needed and mentioned that this gave the possibility to build on ground with temporary building permits. The *innovation project interviewee* also talked about the flexibility with floor plans and how modules could be added or removed if necessary.

The prefabrication of components in factories also provides a better and safer environment for workers. The *traditional construction interviewee* emphasized about the reduced hazardous on-site situations which the *semi-industrialized construction*

interviewee further elaborated on, the factories reduces the heavy lifting and can provide a much better ergonomic for workers.

Moreover, the controlled factory environment eliminates the effects of weather, both from a safety aspect but also from an environmental aspect. The *modular construction interviewee* described the reduction of waste as a consequence of off-site production. This is not solely due to weather but is also an implication of the arrangement in factories. For instance, if timber panels are too long and needs to be shorten, the by-product can be placed in a dedicated recycling area in the factory to be reused or recycled as stated by the *modular construction interviewee*.

The *modular construction interviewee* argued that modular construction can have a positive impact on employments. There is a shortage of construction workers in the cities, simultaneously the rural areas are struggling with few job opportunities. By placing the factories in cheaper rural areas, more job opportunities are created while the competition for construction workers in cities reduces. Furthermore, the *modular construction interviewee* claimed that these factories does not require trained craftsperson but rather lower trained fitter, thus, both provide job opportunities for lower educated people and reduces expenses.

5.3 Challenges with modular construction

Regarding modular construction, the challenges were experienced differently by the interviewees, with the *traditional construction interviewee* and the *client interviewee* being involved in problematic projects before. However, all the interviewees did identify issues with modular construction but from different aspects.

According to the *modular construction interviewee* the development of modular construction is completely dependent on the market and its demand. If the demands from customers cannot be fulfilled with modular construction, the market will shrink and so will the usage of modular construction. The *semi-industrialized construction interviewee* agreed but also added about the issues with detailed development plan in cities which restrict some solutions, and further described the situation during the 90s where detailed development plan and regulations forced their company to have a very flexible system. That is the reason for their approach to be less industrial than their competitors today. This flexible system also means higher project design costs, however, it does give them the possibility to construct the building exactly as big as the permit allows since they are not completely restricted by the size of the 3D-volumetric modules. Nowadays, transportation regulations affect the size of modules as stated by the *modular construction interviewee*, who also would like to have the possibility to have wider 3D-volumetric modules on the road without special permits.

Another challenge with modular construction is described as the development of standardized processes and work methods. The *semi-industrialized construction interviewee* explained about the necessity for their company to develop functioning methods with academia, elaborating that research is conducted in close collaboration with a university of technology. Likewise, the *traditional construction interviewee* and *innovation project interviewee* mentioned the need of optimizing the process, especially during the initial phase of implementation, to identify optimal measures and procedures giving the wanted productivity benefits. Even for companies that have

been using modular construction for a long time, there are still issues which have not been solved yet. For example, the *modular construction interviewee* talked about the waste concerning the double walls phenomena. 3D-volumetric modules need to have four walls to retain its structure, nevertheless, when these are placed beside each other, some places of the building will have double walls consisting of walls from two different modules, as illustrated by Figure 9.

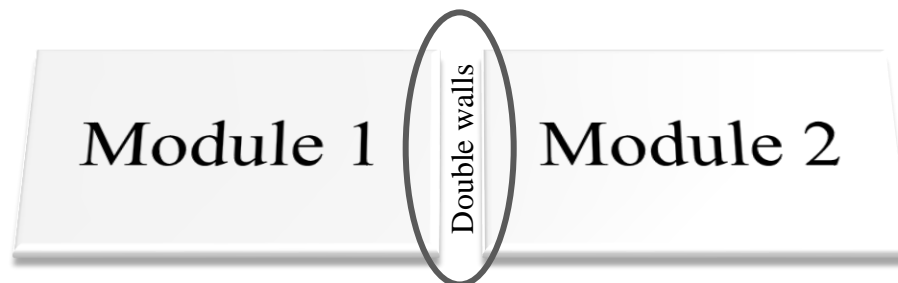


Figure 9 The phenomenon of double walls as described by the modular construction interviewee.

The *client interviewee* and *innovation project interviewee* both mentioned a different way of thinking when using modular construction. With a more detailed and fixed design process but also an earlier decision on the choice of materials and methods. Despite this, the *client interviewee* claimed that the time spent on managing these kinds of projects get reduced if everything proceeds without issues.

Unfortunately, not all projects using modular construction are free from complications. The *traditional construction interviewee* had been involved with projects using prefabricated bathroom pods and mentioned the issues which arose when these were used. For instance, it was difficult to comply with regulations and requirements when using the bathroom pods delivered from the suppliers. These requirements were in some cases a demand from insurance companies. These issues ultimately reduced the usage of prefabricated bathroom pods significantly in their company, however, the interviewee did notice that some projects have been starting to use similar pods again. Likewise, the *client interviewee* observed the high expertise modular construction companies possesses regarding manufacturing of modules but more mediocre concerning problem solving on-site when there are problems with assembling the modules or with the modules themselves.

5.4 Coordination and the design process

All the organizations the interviewees are involved in are in some way using BIM in their processes, with the *client interviewee* emphasizing the inclusion of BIM obligation in their procurements. Even the *traditional construction interviewee* stated that their company design entirely through 3D-models with BIM. Nonetheless, the 3D-model is not used for every step of the construction process, with some activities only using blueprints from the BIM-model. The *modular construction interviewee* also described BIM as a 3D modelling tool rather than a coordination tool, and further mentioned the use of BIM to predict and control different solutions. Additionally, BIM can be used to create the files controlling the manufacturing machineries in factories. Nevertheless, the interviewees noticed the compatibility issues of creating a

unified BIM-model when every discipline use their own choice of preferred BIM software. Still, the *traditional construction interviewee* emphasized the importance of the competences of external consultants rather than their use of compatible software when selecting consultants. Furthermore, forcing external consultants to use specific software usually yield in poor performance and is not recommended. This is something, however, the *modular construction interviewee* does not agree upon. They have a way of working and if that does not fit with external parties, they will have to adapt or be replaced. Hence, standardization is more of an essence for the *modular construction interviewee*.

The *semi-industrialized construction interviewee* reflected over the need for their company to develop software for coordination purposes earlier but is now transitioning to standardized software more and more. The reason for this was that at one point, the software available in the market was not comprehensive enough to handle all the requirements they had. However, they are still developing their own software for coordination. An example of this is their lean based system to make knowledge and information available in real-time. Thus, enabling anyone in the company to extract information and analyse project progression.

The company of the *traditional construction interviewee* does have standardized components and work methods to choose from, thereby reducing their freedom of selecting indefinite solutions. The same goes with modelling using BIM, there is a library of standard elements to select, eliminating the need to design everything from the beginning every time. Nonetheless, the standardization level is not as high as in the company where the *modular construction interviewee* works at. A centrally developed and managed technical platform is used throughout the company, essentially meaning that everyone involved in a project knows which solutions are possible to choose but also removes any freedom to select options not available in their system. Any modifications to this system are centrally organized and accepted by every parties involved. The *modular construction interviewee* further emphasized the clarity this system brings to all the involved actors with no surprises, since everything is detailed and carefully described in this technical platform. Furthermore, the options to select between are few, with the *modular construction interviewee* highlighting the fact that there is only one kind of glue or screw to select from, thus, no surprises will occur. However, for on-site construction, whenever that is necessary, the freedom for the craftsperson to pick a suitable solution is considerably higher. The *modular construction interviewee* acknowledged that this technical platform takes time to develop and many adjustments have been made before it has reached this stage of development. Nevertheless, the coordination has not reached a perfect level as the production speed in the factories could still be optimized. Still, this is a very complex process where a change might slow other processes which could take a long time before being detected.

Regarding the construction of buildings through 3D-volumetric modules, the company of the *modular construction interviewee* uses a standardized library consisting of 24 different modules. The appearance of the modules can be altered by the choice of colour and railings. The idea is that every project should be accomplished with these 24 modules. However, if a major customer requires an additional type of modules, it would be allowed albeit with a higher cost for the customer. These 24 different modules have been developed in cooperation with the

sale department to meet customer demands. The library has evolved during the years and is now version 3, indicating that it is not a completely rigid library.

5.5 Manufacturing of components

The *traditional construction interviewee* described about an area where their company carried out many construction projects during a period of 10 years. Close to that area they built a simple factory to produce prefabricated elements, including walls, floors and roofs. Since they were in this area for a very long period and conducted many projects, it was economically viable to operate this factory. The factory itself was very simple and not automated, instead it provided a better environment for workers and construction materials. At one point, the factory was even moved because the ground it was built on was needed for another project. The *traditional construction interviewee* further mentioned another area where they used to have a factory for production of prefabricated components which were transported to projects nearby, although this factory is currently inactive.

Despite the companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* having an industrialized approach, their production process slightly differs. The company of the *semi-industrialized construction interviewee* has not a fixed system for production of 3D-volumetric modules. This makes the process less industrialized but provides a higher degree of flexibility for their products. Meanwhile, the company of the *modular construction interviewee* has a very strict technical system to ensure that every joint of the modules get a proper connection. This system does not change unless absolutely necessary or only if any improvements are identified.

The companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* both use factories with various degrees of automation and robotics. Some of the factories are highly automated while others consist of manual labour by workers. The *semi-industrialized construction interviewee* described the production on their newest factory almost comparable to the production used in the automotive industry. For example, the walls for the 3D-volumetric modules are produced in a three-zone robotic process controlled by three operators. With this process, raw materials can be transformed into a wall in about 7 minutes and 64 walls can be produced per day. The *modular construction interviewee* depicted their newest factory as highly automated with a 3-axis production line. It is not completely comparable with the automotive industry and lack the 5-axis robot arm, an illustration of the 5-axis robot arm can be seen in Figure 10. However, the *modular construction interviewee* did mention the intentions to, in the near future, implement this kind of 5-axis robot arms in their production process. Both the interviewees stated that the factories were designed to manufacture timber modules only and estimated that a major remodelling would be required to handle other materials.



Figure 10 A 5-axis robot arm similar to those used in the automotive industry. Retrieved from Britannica ImageQuest (n.d.c).

The project the *innovation project interviewee* was involved in used steel 3D-volumetric modules and, at that time, the number of suppliers were limited. Suppliers abroad were considered but the standard dimensions used by them were not in accordance with their requirements and eventually they found a local supplier. Likewise, the *semi-industrialized construction interviewee* has noticed the competitions from manufacturers in other countries which might have a lower production cost compared to theirs due to lower labour costs.

The transportation of 3D-volumetric modules from the factories to the construction sites are not without issues. As these modules can be rather large and heavy, the transportation could be expensive. The company of the *modular construction interviewee* has their factories distributed in different locations around Sweden to be closer to the project location. The company of the *semi-industrialized construction interviewee* has their main factory placed near a harbour to transport the modules through cargo ships. However, only construction sites far away from the factory are using cargo ships as a transportation method. The slower process of coordinating, storing and waiting for ship departures makes projects involving locations near the factory not motivated enough to use cargo ships and these projects get the modules delivered by trucks instead.

5.6 Organizational structure

The companies of the *traditional construction interviewee*, the *semi-industrialized construction interviewee* and the *modular construction interviewee* are conducting their businesses differently. This section describes their way of working and will be further analysed in Chapter 6.

5.6.1 The company of the traditional construction interviewee

The company of the *traditional construction interviewee* uses mostly prefabricated simple 2D-panels for their construction projects. They have a few standardized work methods to choose between and around 8 to 9 different standardized prefabricated facades to use for example. The reason for this is to get a more efficient flow and

reducing the labour hours on-site. The design of the construction process on-site is, therefore, rather limited. However, the selection of software and the processes external consultants use is less restricted, as described in Section 5.4. The same goes with external contractors, the control over their selection of subcontractors, for instance, is limited. The company uses a lot of external consultants and contractors, some profession is even absent in the company, such as the design of installations.

When it comes to testing of innovations in projects or implementing previously proven successful techniques and methods, this is acceptable if the expected outcome is promising, nonetheless, it is very much dependent on the commitments of the individuals in a project team to initiate and engage in this kind of process. The company has created and updating a knowledge database to distribute knowledge and lessons learned among their employees. Nevertheless, the reporting and updating of the knowledge database is a time-consuming task while it is difficult to identify the relevant information needed for a specific project. The *traditional construction interviewee* admitted that in many cases it was just the contact information to someone with the required expertise that was needed and talking with them would provide much better assistance than spending time browsing for useful information. Furthermore, the *traditional construction interviewee* described the department of digital solutions to be very helpful in implementing digital innovations. The persons working in this department were involved in many projects simultaneously and had a better understanding of an innovation and could also be the driving force to implement it to other projects. The *traditional construction interviewee* believed this was more effective than relying on project leaders to implement innovations, as these could be occupied with a project in several years before moving on to the next one.

This construction company has an affiliated company producing residential housing with 3D-volumetric modules produced in their own factory. The *traditional construction interviewee* has been performing some tasks for this affiliated company but otherwise it seems to remain rather independently operating and its factory producing 3D-volumetric modules has not in any higher level been involved in projects conducted by the company the *traditional construction interviewee* works at.

5.6.2 The company of the semi-industrialized construction interviewee

Now, proceeding to the company the *semi-industrialized construction interviewee* works at. The construction process is estimated by the *semi-industrialized construction interviewee* to be around 60 percent industrialized and 40 percent manual labour by craftsperson. Initially, this company constructed one-storey residential buildings mainly using concrete. However, a crisis with declining demands during the 90s resulted in a shift in their business model. Instead, the focus became to construct timber multi-storey residential building using an industrialized approach. Unfortunately, during the 90s the external consultants with the knowledge or will to design in an industrialized way were limited. Therefore, they needed to develop and use their own employees to implement an industrialized process. The result of this can still be seen in the company today, as the *semi-industrialized construction interviewee* claimed they have a higher number of office workers compared to competitors. Compared to traditional construction companies, they also outsource significantly less.

3D-volumetric modules ranging from 4 m² to 35 m² are manufactured in their own factories. They have 3 factories, one is highly automated, the second involves both automated processes but also manual tasks while the last factory is more or less for manual labour only. The placement of these factories did not have a strategic consideration regarding distance to raw materials or market locations. Instead, it was to keep the identity of the company, staying at the area where the company was founded. One of their factories was, however, placed near a harbour for logistic purposes, as described in Section 5.5.

5.6.3 The company of the modular construction interviewee

This section focuses on the company where the *modular construction interviewee* is employed. Construction in this company is based on their 24 standardized 3D-volumetric modules, although supplemented with 2D-panels and additional timber planks when needed. The *modular construction interviewee* stated that with these 24 modules they have in principal managed to meet the demands from the market. The flow of manufactured modules represents one of the largest in the company and 3D-volumetric modules used to construct about 800 to 900 apartments per year are manufactured in their factories.

Outsourcing is not so common for the tasks involved in the design process. Some disciplines are an exception to this and external consultants are hired for design of electricity, heating and ventilation. However, the coordination is performed by the employees of the company. Installation of some tasks, for example, electricity and piping is made by external craftsperson in their factories. The construction of the modules in the construction site is fully outsourced to external companies. The concept is to build in an industrialized way, protocols and standards developed by the company are to be followed by external companies. The *modular construction interviewee* emphasized the importance of these to follow their way of working and if they refuse, they get replaced, since the industrialized process would not work otherwise.

The company has four factories, located in different parts of Sweden, in order to be close to their customers. The automation level of the factories differs, they have factories which are more automated but also some which are less automated and provides the ability to produce more flexible products. Two of their factories can produce the same kind of 3D-volumetric modules, allowing them to get twice as many modules for projects when needed. They have factories which only produce 2D-panels and in their corporate group they also have factories producing different kinds of packaging using 5-axis robot arms. Therefore, the *modular construction interviewee* stated that the knowledge of operating these can be found within their corporate group.

6 Analysis

The findings from the literature review and empirical research are compared and analysed with the basis of the theoretical perspectives described in Section 3.2. With the information obtained from the analysis, this chapter concludes with a section describing a possible way to increase the utilization of modular construction.

6.1 The perception of modular construction

As demonstrated in Section 4.1, Section 5.2 and Section 5.3 modular construction induce both possibilities and challenges. From the interviews, it was apparent that the possibilities were recognised regardless if they used modular construction in their daily operation or not. A quick on-site construction process, better work environment and productivity increase were acknowledged which was also mentioned in the literature.

When it comes to the challenges, however, the opinions were a little bit more diverse. For instance, the *traditional construction interviewee* and the *client interviewee* had negative experiences with modular construction and were more sceptical on its technical abilities to provide a functioning building. The *semi-industrialized construction interviewee* and the *modular construction interviewee* had experience projects using modular construction in a successful manner and were less suspicious about its technical performance. The *innovation project interviewee* even mentioned fear of getting issues related to the use of 3D-volumetric modules, such as noise problems in the apartments or mould growth due to leakage around the module joints. Nevertheless, the *innovation project interviewee* emphasized that no such issues appeared and was happy to show that construction using 3D-volumetric modules can function without any major issues. Hence, employees in a company that might have experienced major issue regarding the use of modular construction may need persuasion to select modular construction for a new project. If they finally engage in modular construction projects which are successful, they could eventually become the ones persuading others to follow.

Of the interviewees that were more optimistic about modular construction, the concern was not so much about their technical abilities but instead it was the complexity related to the use of modular construction. Both the *semi-industrialized construction interviewee* and the *modular construction interviewee* acknowledged the possibility to make the design and manufacturing processes of modular construction more efficient. However, both also recognized the complexity and how the change of one activity potentially could affect productivity negatively. Thus, indicating that modular construction has not reached a stage of perfection yet. It is notable that any decisions of implementing modular construction needs to be aware of the need to constantly evaluate, develop and fine-tuning the process. Currently, modular construction is simply not something that can be implemented with a universal roadmap and functioning flawless at once.

From the interviews, it was discovered that modular construction needed another mindset compared to traditional construction. For example, the *client interviewee* highlighted the need to decide on the design of building earlier and less flexibility for changes. Furthermore, the findings in the literature review indicated that modular

construction requires another way of thinking, namely, a more machine-oriented and product-based approach. The process to shift the mindset among employees requires support and management, in accordance with the theories of change management. Thus, an additional factor to keep in mind.

6.2 Coordination

The coordination and design of a building has in the literature review been focusing on the role of BIM and its implication. In theory, BIM has the potential to be the only tool needed to both design and coordinate with all data available for every team member to use. However, the findings from the interviews indicated that the role of BIM was less prominent than imagined. Obviously, BIM is still an important tool and its implementation, even for the company of the *traditional construction interviewee* which does not construct with modular construction, means it is still useful from many perspectives. Nonetheless, both the company of the *semi-industrialized construction interviewee* and the *modular construction interviewee* use supplementary tools to coordinate their work processes. Information and track of progress, nevertheless, seem important with the *semi-industrialized construction interviewee* mentioning developing their own system to share data in real-time.

For building design, the role of BIM seems more dominant. Modelling building in 3D with BIM seemed to occur even for traditional construction projects. The coordination of building design between different disciplines and the possibility to standardize design elements to reduce workload, and thereby increase productivity, seemed appreciated and applied.

Findings from the interviews indicate that the importance is not how to solve the design and coordination issues but rather that it does get the attention needed. BIM might be comprehensive enough to be the solution but if the available BIM software are deemed to be insufficient, supplementary tools can be use or developed. Noteworthy, is that developing own software could fit the operations and fulfil the needs of the company better, thus, improve productivity and facilitate implementation but requires tutoring for new employees. Standardized software, such as BIM, provides a greater knowledge availability and new employees may not require additional training. As stated by Navaratnam et al. (2022) in Section 4.1.4, if only a small group of practitioners is involved and higher education studies do not educate about a concept, knowledge gap might arise. This can be said both about BIM and modular construction.

6.3 Manufacturing of components

Moving construction off-site to factories where production is mainly performed by manual labour would most likely be easier to implement than using automated production with machineries or robotics. This provides the possibility to move construction workers directly into factories where they would conduct the same kind of tasks but in a more comfortable environment and with a higher stability regarding their geographical location. As their tasks and required knowledge would remain mainly the same, resistance to this change might be less resilient. However, from a lean perspective, this is not as efficient as replacing the workers with a more automated approach. Nonetheless, automation requires investment in machineries and

knowledge which may produce more resistance, as it is not only a matter of change in work routines and culture but eventually the need of a different skill set.

Manual production with labour forces, either with craftsperson or fitters, provides a flexibility regarding factory location but also machinery investments. As described by the *traditional construction interviewee*, their company used a simple factory for prefabrications. A factory which was even moved to another location at one point, this would have been considerably more difficult with an automated factory. Besides, manual production can share factory space with other operations and a combination of prefabrication factory and construction consolidation centre might be possible. The shared space between the factory and the consolidation centre could be more flexible altered compared to having a more automated production with lots of heavy machineries.

The companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* both have factories which are automated in various degree. Both also stated that these automated factories could only process timber, any other material would require major rework of the factories. For a construction company which seeks to implement modular construction but does not want to be restricted to one material, they could use factories with manual production. Furthermore, manual production offers the flexibility to produce less standardized products, something that the companies of both the *semi-industrialized construction interviewee* and the *modular construction interviewee* exploit. This is one of the reasons for these both companies to also have production of prefabricated elements with manual labour.

It is important, however, to note that too much utilization of manual production reduces the productivity benefits obtained from modular construction. The *semi-industrialized construction interviewee* acknowledged the fact that their production was about 60 percent industrialized and provided them the benefit of being more flexible and offering customers more suitable buildings. Nevertheless, the costs of this is higher and productivity was lower compared to competitors using a more industrialized approach. The balance to find the proper degree of industrialization and flexibility needs to be evaluated and weighed up to fit the intentions with the implementation of modular construction. Nonetheless, aiming to achieve 100 percent industrialization, also seems difficult, the company of the *modular construction interviewee*, for example, still needs to use craftsperson both off-site and on-site for some minor tasks.

The location of the factories is another important aspect. The literature suggested that multiple factors can affect the desire to place a factory at a certain location. Closeness to raw materials or distance to markets can be vital factors. Interestingly, the company of the *semi-industrialized construction interviewee* decision to place their factories were not based on strategic factors but instead it was to keep the company's identity by staying in the area where it was founded. Nonetheless, this place of Sweden happens to also have a rather rich access to timber. Thus, the placement of these factories is not completely wrong from a strategic point of view. Furthermore, one of their factories was placed near a harbour to facilitate transportation by cargo ships, indicating that factory location might have been carefully planned after all.

The companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* own and use several factories. However, they both only have one factory which have a higher degree of automation and where investments have been made on implementing robotics. Evidently, the investments needed for these automated machineries surpass other factors. If a company decide to start several factories, it might be wise to plan for a central main automated factory and the supplementary factories being placed at strategic locations and being less automated. The factories should not be considered as independent factories producing different prefabricated elements. Instead, they should act as a unit and complement each other, precisely as the factories where the *modular construction interviewee* works at. They have two factories that can produce the same kind of modules for projects that requires many modules during a short timeframe.

6.4 Organizational structure

Comparing the company of the *traditional construction interviewee* with the company of the *semi-industrialized construction interviewee* or the *modular construction interviewee*, the two more industrialized companies have a much stricter control over the construction process. The company of the *traditional construction interviewee* offer project members a much higher level of freedom to perform their tasks as long as they deliver the expected outcomes. The companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* also offer this kind of freedom when it comes to activities that are at the end of the manufacturing process, where deviations do not affect the production too much, example of this is on-site activities. However, when it comes to processes that succeeding activities are dependent on, the control is much more rigorous. They have developed a system dictating how to perform tasks and this must be followed to avoid errors. Thus, outsourcing is less common for these two companies. Some tasks are outsourced, nevertheless, the coordination is still managed within the company and external companies are expected to follow routines set by them as stated by the *modular construction interviewee*. This is also something identified in the literature, where modular construction companies more frequently have a greater control over the whole construction process. The stricter control provides a bigger chance to influence the process into becoming more successful and lean, however, implementing a strict work process might be challenging and prone to resistance from employees.

The level of freedom for project members working for traditional construction companies might be a bigger illusion than expected. The *traditional construction interviewee* described the limited choice of standard elements and standard work methods, indicating that even for companies using more traditional form of construction, they are not completely unrestrained. Naturally, the restrictions are less evident compared to the more industrialized companies. For instance, the *modular construction interviewee* emphasized the fact that there was only one kind of glue or screw to choose when selecting a certain solution. Nevertheless, if employees in a traditional construction company accept the prevailing limitations, this means that at some stage, a change to limit the possibilities have been made and accepted, with that in mind, an additional change to further limit the options might not sound too distant as initially imagined.

6.5 The way forward?

A rough summary of the challenges to convert into using modular construction would include the need of a change in the mindset of employees, development of the infrastructure to utilize modular construction and convincing employees to use this technology. The *traditional construction interviewee* described the issues with a functioning knowledge transfer within a company but also how digital innovations were successfully implemented with the help of an accommodating department of digital solutions. The company where the *traditional construction interviewee* works at has successfully implemented BIM, thus, the role of this department cannot be completely neglected.

A possible way forward for companies seeking to implement modular construction could be to establish a department focusing solely on modular construction. Initially, the department would function as a research and development department. In this phase, the tasks of the department would be to design and build the infrastructure needed to conduct modular construction. Investments in this department could be considered as research expenses, an investment for the future. Decisions about coordination tools, factory locations and automation level need to be made.

When this process is finished, the task for the department would be to conduct pilot projects in order to fine-tune the developed system. As the number of projects increases, employees from other departments could be involved and assist. The benefit with employees joining the department for some projects instead of outsourcing the project to other departments is that the culture of using modular construction is already established. Individuals joining the department would need to adapt their mindset to an industrialized approach, the prevailing culture in this department. Changing the culture, or institution of a department, is far more difficult than changing the minds of individuals. Depending on the number of projects, employees could be transferred in and out of the department. This would provide labour needed for the department to accomplish their projects but knowledge would also transfer to other within the organization.

Finally, when the developed system has reached an acceptable level but also enough employees have been involved with this department and the knowledge about modular construction is more widespread within the firm, the department could transform into having a role similar to IT departments. An alternative is that the group of individuals with the core expertise of modular construction moves to a new department with the task to have a similar role as an IT department. With the expertise they gained from designing the system and conducting several projects, the department can assist employees when needed but also developing and updating the infrastructure to improve performance. If needed, also conduct pilot projects to further develop the system.

7 Discussion

In this chapter, all the major findings so far and the suggested way forward are discussed and contrasted by having a more holistic view. The discussion is not limited to the theoretical perspectives used in this report and intends to explore modular construction and its implications from a holistic perspective while also discussing the possibilities and drawbacks. The intention with this chapter is not to conclude in any best practise, if considering finding a best practise something even possible to do. Instead, it serves to increase the awareness of the consequences of different options, since the complexity of the real world rarely allows one perfect solution which fits it all.

7.1 Investing in modular construction

Modular construction, with all the potential benefits and with challenges possible to overcome. Surely, investing into becoming a company utilizing modular construction should be an obvious and sensible decision. Indeed, industrialized construction companies have managed to implement modular construction in a successful manner and the *modular construction interviewee* even estimated a cost reduction of over 10 percent compared to traditional construction. Likewise, Bertram et al. (2019) estimated a cost reduction of up to 20 percent derived mostly from reduced material and on-site labour costs, however, with a risk at 10 percent increase due to higher off-site labour, factory costs and logistics among other things. Hence, modular construction is no way a guarantee for a successful investment. Using modular construction in a proper manner could yield cost saving but misjudgements in planning and execution might instead increase time and cost for the company.

Liu et al. (2021) described the need of an excessive product mix with a combination of materials in different sizes required to create 3D-volumetric modules. The need of so many kinds of components risk resulting in a disturbance in the production line with some stations overloaded with tasks while others are vacant. The productivity growth by using prefabricated elements could in this case be diminish completely. This highlights the need of an effective coordination of all processes, if modular construction is going to provide the benefits it potentially could yield. Errors in the process or information handling might eventually result in such a significant productivity loss that investments into applying modular construction might be deemed an economic failure.

Precisely as the design and production phase of modular construction, careful planning is needed when the decision to implement modular construction is made. The *semi-industrialized construction interviewee* emphasized their use of more office workers than traditional construction companies for planning, designing and coordinating processes to enable modular construction. The same needs to be done for the process of implementing modular construction in a company. Hall et al. (2022) emphasized that modular construction requires investments in factories and technologies which cannot be recovered within the scope of a single project. Therefore, modular construction and the infrastructure it requires, should be considered from a more holistic approach where the investments can benefit a company in the long-term rather than producing rapid productivity growth and cost savings.

One of the biggest construction companies in Sweden, NCC, had conducted a project to utilize modular construction with the name NCC Komplet (Bock & Linner, 2016). A factory was established, with the potential to customize concrete walls and modules completed with doors, windows, radiators, switches and even kitchen furniture. Concepts such as just-in-time were used and an on-site mobile assembly hall was even created, all this during the middle of the 2000s (Bock & Linner, 2016). However, the project did not last many years before it was ended because it was deemed yielding poor return on investment (Jensen et al., 2012). Thus, a clear and detailed plan of the goals and outcome of the investment should be made prior implementation but also how to reach the short-term goals to achieve a sense of success, as described in Section 3.2.2 with Kotter's 8 step change model. Without short-term success, the patience might be lost and the outcome risk become like the project of NCC Komplet.

7.2 Importance of modular construction

Considering the economic risks described in Section 7.1, the question remains if construction companies should even transform into using modular construction. Evidently, there have been unsuccessful attempts before and implementing modular construction is associated with high initial investments, especially if no processes are outsourced.

Nonetheless, modular construction as a technology has reached a high level enough for specialized companies to build their business models upon, as described in Section 4.4.2. Therefore, it could be debateable whether traditional construction companies can afford to ignore modular construction. It might be economic safer for traditional construction companies to invest and improve on methods used for traditional construction, but the question is if the productivity gain from this can compete with the industrialized approach obtained by modular construction. At some stage, these specialized companies might develop their modular construction techniques to a certain degree where they could compete with traditional construction companies, even for more complex markets. This could be compared with the case of Nokia, which had a high market dominance before the release of Apple's iPhone. Nokia did invest heavily on research and development the year before and some years after the release of iPhone (Alibage & Weber, 2018). However, the focus of the research was to improve a product that just could not compete with a smartphone. In the same manner, research on improving traditional construction processes and methods risk rendering useless if the industrialized approach simply is far more productive.

From a sustainability aspect, modular construction could improve the performance of all three aspects of sustainability, specifically, environmental, economic and social factors. Construction companies that strives to act and present themselves as a sustainable company and showing no interest in modular construction might give their customers a confusing perception of the real intentions of the company. Similarly, society might question the company's view on workers' safety when there are possibilities to significantly improve their conditions and no interest is shown by the company.

7.3 Market demands

As the *modular construction interviewee* described it, modular construction cannot exist if it fails to deliver results expected by customers. As described in Section 3.1.1., modular constructed buildings have been constructed to many different kinds of buildings, some are more primitive while others can be quite impressive. Modular constructed buildings are not seldomly associated with ugly design, something that might be caused by the possibility to build very primitive buildings with 3D-volumetric modules. However, Linner and Bock (2012) depicted the Japanese market for modular constructed buildings to be targeting the middle and high-end market, with these buildings associated with positive attributes, such as earthquake resistance. Therefore, it could be debatable if the market rejects modular constructed buildings or if wrong technologies are used for markets which are not appreciating these kinds of buildings. Evidently, the technology to construct modular buildings in a satisfactory manner exists, perhaps the issue is not with modular construction as a concept but rather the execution of this concept. Hence, if there are fears of weaknesses with modular construction as a technique to provide adequate products, feasible solutions are already existing albeit with reduced productivity as a consequence.

7.4 Flexibility or productivity

Many of the choices for modular construction is about balancing between having flexibility or increasing productivity. This applies to design process, manufacturing process and the appearance of the product. The companies of the *semi-industrialized construction interviewee* and the *modular construction interviewee* have selected different paths and they used different level of industrialization. When implementing modular construction, decisions regarding this dilemma needs to be addressed, as it may impact the results. Higher flexibility means an increased possibility to fulfil customer satisfaction, but too high flexibility might eliminate the benefits with modular construction altogether.

7.5 Outsourcing

A construction company deciding to utilize modular construction has the possibility to keep every step of the process within the company or using external companies to reduce the risks and workload. If the manufacturing process is outsourced, this basically transform the construction company to a consultant in construction projects, as up to 90 percent of the construction is transferred to the factory (Johnsson & Meiling, 2009). Meanwhile, if the design phase is outsourced, the construction company essentially becomes a supplier. Full control over the whole modular construction process would instead give the company the possibility to henceforth offer design-build contracts or turnkey contracts, thus, being a company which a client can approach to obtain a building without the need to be further involved in the project. Furthermore, different choices require different level of investment but potentially could also affect future market share, especially if modular construction becomes the norm for the whole sector.

Globalization is another topic that might affect the decision to establish a factory for production of prefabricated elements. The *semi-industrialized construction interviewee* mentioned the competition from nearby countries producing 3D-

volumetric modules with cheaper labour costs. While the 3D-volumetric modules are rather heavy and large, if the logistics of these are developed, it is not impossible that they can be produced from countries far away where production costs can be lowered. In the same way as smaller products being produced in countries with low costs, this might potentially be something occurring more frequently in the future for 3D-volumetric modules. For example, one of the factories in the company where the *semi-industrialized construction interviewee* works at is close to a harbour and they ship some of the 3D-volumetric modules with cargo ships. If the same factory was placed in a country with lower production costs and the cost for transportation with cargo ships is low enough, these modules might be cheaper than locally produced modules.

7.6 Moral aspects

With such a radical change as becoming industrialized encompasses, a different kind of mindset and skills might be required. Thus, some may find it difficult to accept, especially if their position and power gets negatively affected. Moreover, the question is if the frequent time and cost overrun occurring in the construction sector is something every company wants to eliminate, some may even benefit from this. Therefore, the question remains if modular construction is a development appreciated by everyone.

7.7 The suggested solution

In Section 6.5, a possible way to implement modular construction was described. Here, it will be further discussed and explored.

Basically, the idea is to move individuals into a culture of industrialized construction approach instead of forcing this mindset into a group of individuals which might resist due to another prevailing culture and mindset. Nonetheless, an important aspect with the described way of implementing modular construction is that it assumes that a culture or institution actually exists and affect employees, an invisible force acting on the involved members towards a certain behaviour. It also assumes that the culture of the department is acting in a way that benefits implementation of modular construction. However, the department consists of individuals which all in some way can affect the prevailing culture and perhaps in an unexpected direction. Therefore, the success of the department in implementing an industrialized mindset among employees is largely dependent on the composition of the individuals and their behaviours within this department, something that might even change over time.

Additionally, the knowledge gained within this department is expected to remain there even when employees in the department leaves, hence, the knowledge is anticipated to be a property of the department rather than at the individuals. Naturally, this needs to be addressed by, for example, educating employees before replacing others or replacing employees with new employees that have similar knowledge.

Furthermore, during the fine-tuning phase, it assumes that the department conducts projects in such a manner that they do have time and effort to educate and train employees into working with a modular construction process. The goal would not be solely to achieve project success to all costs.

The advantage with the department ending up with a similar role as an IT department, is that the implementation phase does not only entails of an implementation project to create a functioning infrastructure of modular construction and the phase of educating employees. Instead, it remains a centre for knowledge transfer and problem-solving for the company but also a safety for employees which feel unsettled regarding the shift to industrialization and modular construction. Nevertheless, this means an additional cost compared to using an implementation project which disbands after implementation of modular construction.

Notable, is that this suggestion is a concept that needs to be further researched and tested, as it has not been implemented in any organization yet. The suggestion is, therefore, not a guarantee for a successful implementation of modular construction.

7.8 Future research

A topic for further research would be to estimate the costs of all the investments needed to enable the utilization of modular construction and how the funding should be accomplished. Moreover, different business models can be explored, from a financial aspect, to determine the most profitable way of implementing modular construction. The findings could be put in contrast to the cost savings obtained by modular construction. Data from this can support the decision makers of companies to estimate the profitability of moving towards a more industrialized construction. If the research results conclude in financially viable options, the motivation to invest in such technologies might increase. Furthermore, in-depth research to determine the consequences of different technical solutions can be made to increase the knowledge of the complex processes of modular construction and how to make it even more efficient. Additionally, all the stages of the modular construction process, such as the design and manufacturing phase, can be optimized through technical developments.

8 Conclusion

Traditional construction, where most of the construction work is performed on-site using construction workers is one of the reasons for the low productivity the construction sector is associated with. By moving towards an industrialized approach, the construction industry could achieve some of the productivity growth obtained by other industries, such as the manufacturing industry.

Modular construction consists of off-site prefabricated 2D-panels, 3D-volumetric modules or a combination of both to be transported to construction sites for assembly. The benefits are widely accepted and includes increased productivity, reduced waste but also improved safety and work environment for construction workers. Thus, modular construction could facilitate the transition to a more sustainable development for the construction industry, concerning all three aspects of sustainability which involve environmental, economic and social aspects.

The design process needs adequate planning and coordination. BIM has the potential to be the only tool required to coordinate the building design but also to share data and information among project members. However, the existence of own developed system to handle some of the functions BIM potentially could handle has been identified and seem to work sufficiently. The importance is, therefore, not to force an implementation of a technical system for coordination but to find a solution which facilitates the coordination for every step of the modular construction process, including the manufacturing process. Coordination and access to information and progress is so vital that real-time sharing of this data was expressed as a desirable development.

Manufacturing of prefabricated components can be achieved through different options. Manual labour in off-site factories requires less investments and provides flexibility regarding design and material. Nonetheless, this also means lower productivity. Automated factories require less labour forces but limits the choices for the building design. Furthermore, machineries and robotics requires substantial investments and are more difficult to relocate. An option would be to have multiple factories with various degree of automation to provide flexibility but also gives a more strategic placement of factories concerning distance to raw material and project locations.

Standards needs to be developed and decisions needs to be made whether to focus on flexibility or productivity, which also translates into customer satisfaction or profit. Standardization applies to both the design and manufacturing process, thus, reducing labour requirement. However, the development and improvement of the standardized processes demands a high level of office workers.

Decisions also needs to be made about the use of external labour in the modular construction process. The complexity of the design phase has result in industrialized companies deciding to perform most of the task themselves or with rigorous control over the outsourced activities. The manufacturing procedure entails up to 90 percent of the construction work, outsourcing this process ultimately transform a construction company into a consultant.

A possible way forward to transform a construction company using traditional construction methods was suggested. This concept includes establishing a department responsible for developing an infrastructure in which modular construction can be utilized. This involves making decisions and creating coordination tools, factories and strategies for the modular construction process. The department can be considered as a research and development department, hence, the investment would be for the long-term.

When the infrastructure to utilize modular construction is developed, the department could manage pilot projects to improve this infrastructure. Employees from other department would join to provide required labour. By joining the department, which has a culture of industrialized mindset, the process to learn and alter their own mindset facilitates. Consequently, knowledge about modular construction process is spread within the company. The future of the department is to, at one point, convert into a role similar to IT department, to improve the infrastructure but also to assist in projects and help employees solving issues.

9 References

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