The New Norm of Circular Construction

Accelerating successful employment of vertical integration of modular construction's project- and product value chains

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Lister Buildings
THE REAL ESTATE LIFECYCLE COMPANY

TU Delft Delft University of Technology

CME5200 - Graduation Thesis X Lister Buildings

The New Norm of Circular Construction

Accelerating successful employment of vertical integration of modular construction's project- and product value chains.

An empirical single case study of an integrated modular building company.

This thesis was written in partial fulfilment of the requirements for the degree of Master of Science (MSc) for the master program Construction, Management and Engineering (CME) at the Faculty of Civil Engineering & Geosciences at Delft University of Technology.

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Preface

It is my pleasure to present to you my thesis research report titled **"The New Norm of Circular Construction**: Accelerating successful employment of vertical integration of modular construction's project- and product value chains". This report represents the culmination of the master Construction Management & Engineering of the faculty of Civil Engineering & Geosciences of the Delft University of Technology and has been conducted in collaboration with circular real estate developer Lister Buildings. The research provides information on the topics of value chain integration of project- and product-based disciplines within the modular construction industry, including the different production systems and other aspects to consider when enabling value chain integration.

As a graduate of Civil Engineering, I have always been fascinated by the impressive high-rise buildings that define the skyline of many cities. However, due to the increasing awareness around the climate crisis and global sustainability efforts, I have been intrigued by the construction industry's enormous impact on the environment and the urgent need for more sustainable practices. With the realization that traditional construction methods can be resource-intensive and wasteful, I became interested in exploring the potential of circular construction methods to promote sustainability and create a more efficient construction process. Thus, a collaboration with Lister Buildings, a circular residential developer using timber demountable modular construction, provided an excellent opportunity to delve into this topic and investigate how to industrialize circular construction methods. The motivation behind this research was to investigate how to industrialize the use of circular construction methods as a way to help the industry's sustainability challenges.

The primary goal of this research is to contribute to the ongoing discourse on sustainable construction and the emerging field of circular construction. Specifically, I aim to provide insights and recommendations that can accelerate the successful employment of vertical integration of modular construction's project- and product-based value chains. This research will be a valuable resource for all stakeholders in the construction industry, including developers, architects, engineers, and manufacturers, who are interested in adopting circular construction practices. I believe that this research will inspire further exploration of circular construction practices, particularly in the modular construction industry, and help to pave the way for more sustainable construction methods in the future.

This research has been conducted under the supervision of Prof. Dr. ir. Hans Wamelink, Dr. ir. John Heintz, and ir. Arie Bergsma. I conducted this research work from August 2022 to February 2023.

If you are interested and would like to know more about vertically integrating value chains in the modular construction industry, please continue reading.

Sarah Vafa,

February, 2023

Executive Summary

The construction industry faced a significant slowdown in sales and revenue growth in 2020 due to the impacts of the climate crisis and the COVID-19 pandemic. Although the situation has improved in recent times, the market still remains uncertain due to various challenges such as personnel shortages, and the rise in building material and energy costs.

In order to overcome these challenges and foster a sustainable future, it is important that the government and regulatory bodies take the lead in directing and incentivizing the market. The National Environmental Vision (NOVI) in the Netherlands is a government-led strategy aimed at promoting a sustainable living environment through policies and regulations that incentivize the use of circular and sustainable building practices. Modularity is one of the ways to encourage the adoption of sustainable and circular business models in the construction industry. Modular construction has once again gained popularity in regions with high housing demand and labour constraints in the construction industry. The current surge in interest in modular construction may indicate that the movement is here to stay, but only if there is a balanced foundation that supports both construction and manufacturing approaches.

Ribeirinho et al. (2020) conducted thorough research and found that the leading shifts in the construction industry include a switch from a project-based to a product-based strategy and value chain control. To industrialize the construction market, a new entrant with a production approach suitable for modular construction and a vertically integrated value chain might be one of the ways to Rome.

The aim of this study is to enhance the productivity and efficiency of the modular construction process by providing practical recommendations on fostering collaboration between the various actors involved in the value chain, including developers, architects, system engineers and manufacturers. This research will focus on examining the feasibility of integrating the value chain in modular construction projects and identify the challenges or success factors for implementing it in practice. A deeper understanding of different production systems will be crucial in determining their impact on cross-functional relationships. This study will provide valuable insights into the modular construction process by either confirming or disputing claims about the integration of the value chain. The ultimate goal of this research is to improve the modular construction process by delivering actionable insights that can be used to enhance collaboration and increase efficiency.

The study is designed in two phases. The first phase will involve conducting a comprehensive literature review to gather information on the current state of modular construction, the various production systems that exist in the manufacturing industry, and a deep dive into integrated value chains. Additionally, the phase will involve exploring the benefits and challenges of traditional and modular construction, standardization, and developing a preliminary list of critical success factors (CSFs) that drive cohesive organizational integration.

The second phase will use the findings from the first phase to develop a list of factors that will help industry experts improve alignment and integration throughout the value chain in modular construction projects. To this end, a single case study with a modular construction company will be conducted to analyze the experiences of operating within such an environment and to validate the previously established factors and production systems. By utilizing the insights gained from the study, it is expected that recommendations for improving the productivity and efficiency of the modular construction process will be provided.

Findings

The modular construction industry faces the challenge of integrating its value chain in order to achieve efficiency, productivity, and profitability. The case study of Lister Buildings, a modular construction company, revealed several critical success factors (CSFs) that are relevant to the entire industry. However, the main conclusion of this study is that the modular construction industry is currently facing an identity crisis as it tries to merge two conflicting disciplines: project and product.

Synergy

Modular construction allows for the pre-fabrication of modules in a controlled factory setting, which can lead to higher quality and greater efficiency compared to traditional construction methods. However, this also presents difficulties such as coordination and communication between team members who may have diverse backgrounds and be working from separate locations. This study explored ways to improve the integration of the value chain departments to overcome these challenges.

Competency

The study found that "adequate experience in the modular construction industry" is essential for fostering both a standardized, product-oriented approach and a project-oriented approach to balance it out with customization. This combination of approaches would provide the necessary design flexibility to meet clients' needs, ensure design consistency, and streamline the production process. The study suggests that the modular construction industry could benefit from developing a set of pre-defined standardized modules which can be configured to create various apartment designs. This approach requires a make-to-order or assemble-to-order production system. The top-ranking CSFs, such as "defined design & technical specifications of the product" and "scalability through standardization and product configuration," are also important features of the product environment.

Organization

Coordination was found to be a critical tool for managing the value chain and fostering integration between cross-functional departments. The data showed clear misalignments due to the merging of two conflicting disciplines in the industry. The shift from a project-based approach to a product-based approach brings its own complexities and requires a change in decision-making from the developer/designer to a developer/designer/manufacturer combination. The top-ranking CSFs for organization include "early involvement of key parties," "effective alignment on responsibilities and expectations," and the "link between project/design and product/production" to facilitate collaboration.

In conclusion, the future success of the modular construction industry lies in striking a balance between two opposing disciplines - project and product. This requires a cohesive approach, which can be achieved by creating synergy between the two. Clear communication, collaboration, and information sharing are essential in building a supportive culture that enables both disciplines to flourish. Moreover, effective management is critical in fostering clear coordination and alignment within the teams to support the differences in disciplines throughout the process.

In terms of the future of the modular production strategy, this will depend on various factors such as the organization's goals on product, production and organization, resources, and market demand. Some organizations may opt for a project-based approach, while others may prefer a product-based approach. The former emphasizes delivering unique projects that are tailored to the specific needs of the client, while the latter focuses on efficiency, cost-effectiveness, and profitability, and involves a long-term internal team structure, strong external relationships with suppliers and partners, and a focus on production rate, design type, and product configuration.

Keywords: modular construction, value chain integration, product-based, project-based, production systems, construction, manufacturing, cross-functional departments.

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Abbreviations

CSF – critical success factor

CSFs – critical success factors

MC – modular construction

VC – value chain

SCM – supply chain management

VCM – value chain management

SCI – supply chain integration

VCI – value chain integration

LB – Lister Buildings

LD – Lister Development

LA – Lister Architecture

LO – Lister System Engineering (Lister Systeem Ontwikkeling)

LM – Lister Manufacturing

SG – Stage Gate


Source: Lister

1

Introduction

1. Introduction

This chapter elaborates on the global and national trends and factors shaping the construction industry. According to the UN Special Rapporteur on “the Human Right to Adequate Housing", a house is the foundation of stability and security, the focus of most people's social, emotional, and even economic lives - a place where one “has the right to live […] in security, peace and dignity” (OHCHR, 2014). In recent years, the housing market has been under pressure due to growing demand for (inner-city) housing and a lack of supply. Housing is in high demand as a result of factors such as population growth, rapid urbanization, smaller households, the freezing of "mobility in houses, and so on. The low developing speed to cater to these issues might instigate an investigation into possible adjustments to the current building methods to increase the rate of housing production. One potential solution to meet these needs and challenges could be the use of modular prefabrication.

1.1 Population growth and rapid urbanization

At the time of writing, The Netherlands has 17.7 million citizens dispersed in 8.1 million houses (CBS, 2022). It is expected that in 2038, the number of homes will have increased to 9 million to accommodate the expected population increase to 19 million citizens. (Rijksoverheid, 2022c). Overall, the population rose by 67 thousand, about half as much as in 2019 and more than 30 thousand less than the yearly average from 2015 to 2019. This reduction, linked to the COVID-19 pandemic, in the population and household growth helped to relief some of the pressure on the housing market.

In 2021, the housing shortage totals 279.000 homes with recent forecasts anticipating an increase to 317.000 units by 2024. The government has declared that it will address the housing shortage by expanding annual house production from 80.000 to 100,000 units (Primos, 2021a). The Construction Agenda currently stipulates that this figure must be met by 2024. Although the number of new homes will skyrocket over the next few years, the number of families is growing at a faster rate, causing the housing shortage to worsen at first.

Figure 1 shows, when the black line becomes hyperbolic, that the housing shortage will peak around 2024 with around 317 thousand homes. Interestingly, there are significant regional variances in the shortages. The regions with the greatest shortages are Utrecht (5.9%), Nijmegen (5.9%), The Hague (5.8%), and Amsterdam (5.7%). Also in the Leiden, Rotterdam, and Tilburg areas, the deficit is 4.5% higher than the national average of 3,9%. This comes down to the ongoing urbanization of the more dense environments (PBL & CBS, 2022).

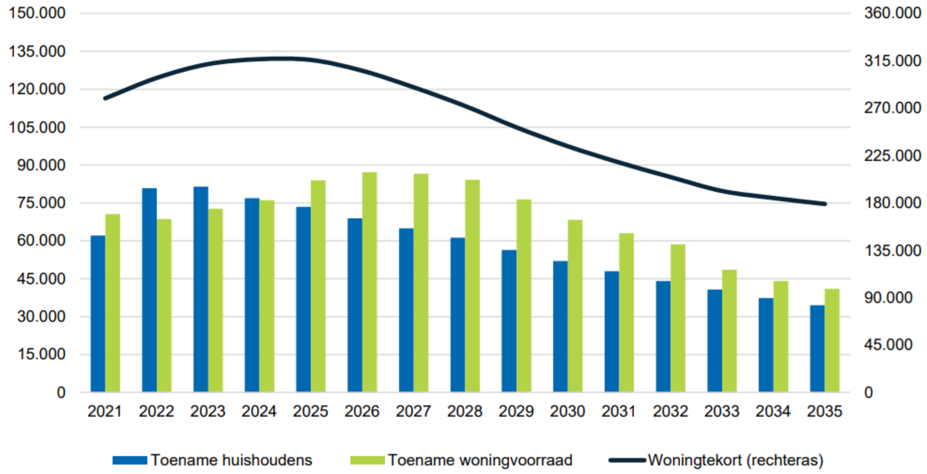
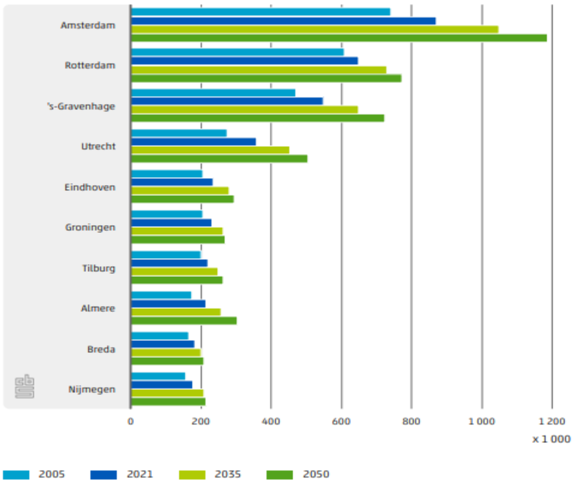


Figure 1 National growth index households, building stock and housing shortage 2021, CBS (2021).

Figure 2. Population increase in the top ten municipalities, CBS (2022).



The four major cities are expanding due to natural growth and immigrant migration. An increase in immigration is also projected in the future, which adds greatly to this. Utrecht is anticipated to grow the quickest of the four main cities, by more than 25% by 2035, followed up by Amsterdam with a growth of 20%. In 2030, the capital is predicted to surpass the one-million-person mark. The Hague and, in particular, Rotterdam is expected to develop at a slower pace, with forecast rises of 18% and 12%, respectively (PBL & CBS, 2022).

1.2 Sustainable change

Creating solutions for the housing crisis calls for developing new residential projects. However, the housing stock is a major contributor to climate change as the sum of energy-related emissions from buildings and construction represented 37 per cent of the global total in 2020, declining slightly from 38 per cent in 2019 (UNEP, 2021).

The Paris Agreement is an international agreement reached in 2015 by the United Nations Framework Convention on Climate Change (UNFCCC) to combat global warming and its negative impacts. The agreement aims to limit the increase in global average temperature to well below 2 degrees Celsius and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius (UN, 2016). One of these efforts is the aim to completely decarbonize the global buildings and construction sector by 2050. Emissions from materials and construction processes must be addressed promptly to guarantee that buildings developed today are optimized for low-carbon solutions throughout their entire life cycle. Overall, buildings accounted for 36 per cent of global energy demand and 37 per cent of energy-related CO2 emissions in 2020. The different ingredients to create this total are depicted in figure 3. The residential sector contributed a total of 17 per cent in energy-related emissions, with another 10 per cent in manufacturing building construction materials such as steel, cement and glass.

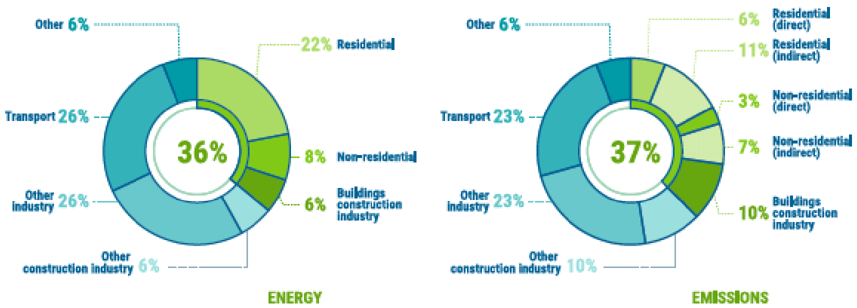


Figure 3. 2021's Building and Construction's share of global emissions (UNEP, 2021)

1.3 Scarcity and rising construction costs

The rate at which construction businesses have been selling and increasing their revenue fell below their typical levels in 2020 due to the impacts of both the climate crisis and the COVID-19 pandemic. Although the situation has improved this year, there is still a high degree of uncertainty in the market due to difficulties due to personnel shortages, rise in building materials and energy costs

1.3.1 Labour

There are now around 26,000 construction job vacancies. That equates to 76 job vacancies for every 1,000 employees. Employers classified more than three-quarters of construction job opportunities in 2021 as "challenging to fill." The intake of fresh personnel is structurally insufficient. (Dirkse & Smit, 2022) Furthermore, an increasing number of entrepreneurs are concerned about a shortage of qualified labour. In the second quarter of 2022, 35% of entrepreneurs in the wood and building materials business had difficulties in this respect. (Bisschop & Wolf, 2022). Although the collective bargaining deal agreed upon in June resulted in the sector's greatest-ever wage increase, 5% over two years, it is likely insufficient to address the labour shortfall.

However, with a 36,000 increase in demand in the year 2020-2025, the overall labour force inflow required for that time is 73,000. In the period 2025-2030, it already flattens somewhat with an expansion demand of 20,000 workers. This has to do with the aforementioned expected decline in building projects due to the increase in the housing stock. (EIB, 2021)

1.3.2 Material

Construction expenses increased 15% on average in the first quarter of 2022 compared to 2021. Prices for wood and metal items surged especially dramatically. Some of these items originate in Russia or Ukraine. For example, numerous significant aluminium facilities in Ukraine have been shut down due to the conflict.

Also, when comparing the second quarter, it shows that more and more enterprises are reporting production resource, material, and space constraints. This was true for 23% of people in the second quarter of 2022, up from 12% in the previous quarter (Dirkse & Smit, 2022). Still, some building materials prices appear to be gradually stabilizing in recent months. Gas, wood, aluminium, and insulating materials no longer exhibit the same outliers that they did shortly after the outbreak of the Ukrainian conflict. However, the overall situation remains unclear, and material costs are still significantly higher than January 2021 levels (Leeuw, 2022).

The rise in material costs is caused by increased energy costs and material supply issues. This has to do with the current Russian invasion of Ukraine and the upholding repercussions of the corona epidemic to cause challenges in the worldwide supply chain (Bisschop & Wolf, 2022).

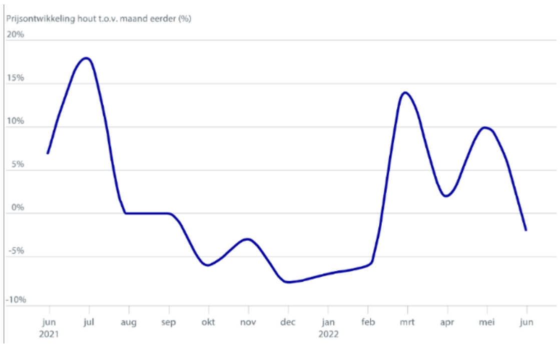


Figure 4 Material price %-increase: timber (2021-2022) (Cobouw Insights, 2022)

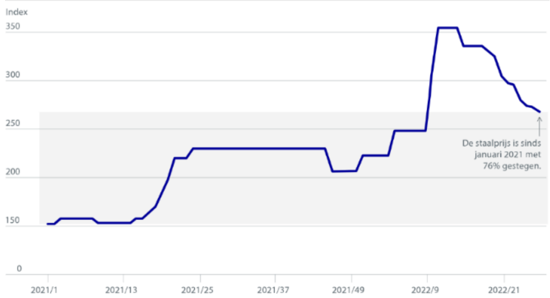


Figure 5 Material price increase: steel (2021-2022) (Cobouw Insights, 2022)

1.4 National governance and policies

The trends described are of such magnitude that national government and regulatory bodies need to direct and incentive the market in order to encourage change. In this collaborative effort, the government takes the lead by directing important goals and fostering public-private cooperation in order to solve societal, economic and environmental issues, as such are described previously.

The National Environmental Vision (NOVI) is a governmental-steered strategy that leads the market to a sustainable view of the future living environment. The NOVI developed urbanization methods to aid in outlining the focus areas to build 80 to 100,000 dwellings annually (Primos, 2021b; Rijksoverheid, 2022a). However, in recent years, an annual average of approximately 70.000 residences have been constructed (Rijksoverheid, 2021). This indicates that the current rate of construction is not meeting the target set by the NOVI. It suggests that there may be challenges or barriers in the current construction process that are preventing the desired level of production. This could be due to a variety of factors from lacking available land to a shortage of skilled labour or materials.

Therefore, the Netherlands government is actively encouraging the construction industry to move towards more circular and sustainable ways of building. One of the main reasons for this is to increase the efficiency and speed of the construction process, with a focus on reducing lead times from planning to realization. This is said to be achieved by streamlining the planning process, increasing capacity and promoting innovative techniques such as conceptual and industrial construction (Rijksoverheid, 2022b). The use of sustainable materials and methods is also being emphasized as a way to reduce the environmental impact of building construction and create a cleaner, safer living environment for future generations.

In order to achieve these goals, the government of the Netherlands employs a variety of policies and regulations that incentivize the use of circular and sustainable building practices such as the Environmental Performance Requirement for Buildings (MPG). The MPG is a set of regulations for the construction industry that control the use of sustainable building techniques and technologies and sets targets for reducing energy consumption and carbon emissions (Ministerie van Binnenlandse Zaken, 2021). Additionally, there are various financial incentives, such as subsidies, which are available to construction companies that adopt circular and sustainable building practices.

1.5 Problem Definition

We cannot address the housing crisis without addressing the climate crisis. This is due to a shared denominator: the underperforming construction industry. The underperformance may be caused by numerous dynamics of the construction industry's performance, such as being fragmented, complex and a major contributor to global pollution. Change within the industry is both difficult and slow as a result of the first two characteristics, external market factors and a general aversion to risk. External factors such as population growth, rapid urbanization, climate change, resource scarcity, and digitalization are the current global megatrends (PwC, 2022). All of these trends have an intersection with the building and construction industry. The building sector is obligated to limit the damaging effects of these trends by supplying sufficient quality housing, whilst transitioning to a more sustainable process to avoid contributing to the climate problem.

The building sector has the potential to fulfil these demands by becoming more product-driven, efficient and sustainable, which are said to be attainable with the use of modular construction (Bertham et al., 2019). However, traditionally, the building industry is characterized as a project-driven industry with unique characteristics such as location-bound design, one-of-a-kind/unique production, changing partnerships per project, outdoor and environmental factors, and multiple clients and suppliers involved in a single project. These characteristics conflict with the product-driven ambitions, leading to negative effects on performance such as low levels of effectiveness and efficiency, low rates of innovation and difficulties in knowledge sharing and learning. In comparison to other industrial sectors, the building industry is considered to have a lower performance level (Al-Hussein et al., 2009; Rahman, 2014).

Fortunately, a product-driven form of the building industry, modular construction has regained popularity in regions with high housing demand and labour constraints in the construction industry. The current surge of interest might imply that the movement is now here to stay if provided a balanced foundation and ability to scale. (De Jong et al., 2015). Experts are already noticing and discussing means to be able to scale the industry. Ribeirinho et al. (2020) discovered, summarized, and validated nine industry shifts through thorough predictive quantitative research. The top leading shifts were to switch from a *project- to a product-based approach* and *vertically integrate for value chain control.* In these cases, all members of the integrated value chain with conflicting disciplines need to have, among others, a solid cohesive organizational culture. Cohesion has been widely recognized as a contributing factor to group and organizational performance and is commonly understood to refer to the closeness or commonness of attitude, behaviour, and performance within a work group (Odom et al., 1990).

The main differences when applying the modular construction approach are the partial allocation of the construction work to an off-site facility and the use of design repetition (Vrijhoef, 2011). A highly repetitive production process, leaning towards a product-approach, allows for greater standardization and simplification of the design, engineering, and manufacturing processes. This, in return, can lead to improved collaboration and integration among the different members of the value chain, as everyone is working from the same standardized specifications and processes. On the other hand, when a production process is less repetitive, it often requires a greater degree of customization and variation. This can make it more difficult for designers, engineers, and manufacturers to work together effectively, as each stage of the process may have different requirements and constraints.

To industrialize the construction market, one needs a disruptive new entry. A new entrant using a product-based approach suitable for modular construction and a vertically integrated value chain may just be the one. But which approach should be applied when the sector descends from a traditional project environment but has resembling characteristics from a product environment? Furthermore, how does one go about vertically integrating the value chain, where to start, whom to consolidate, and how to create cohesion between departments?

1.6 Research gap

There has been substantial research on the benefits, strains, challenges of modular construction and success factors on how to implement it, with a fair amount of comparable studies (Azhar et al., 2013; J. O. Choi et al., 2019; Liu et al., 2019; Rippon, 2011; Tsz Wai et al., 2021). However, it would be of relevance, due to limited literature, to conduct research with the aim of exploring the link between the equilibrium of a project- vs. product-approach and the increasing value chain control by integrated value-chains in the modular construction domain of the Netherlands. The degree of repetition in a production process can have a major impact on the collaboration and cohesive integration of the value chain including designers, engineers, and manufacturers. Therefore it is of essence to gain knowledge of the different production processes with the variables categorically divided between the two extremes: the project or product approach

It is common practice in the manufacturing industry to integrate the supply chain and gain a competitive advantage from it (Vrijhoef, 2011). The modular construction value chain is partly project-based (construction), to enable certain design freedom, and partly product-based (manufacturing), to produce the modules. Due to modular construction having manufacturing features, will it also benefit from the integration of the value chain? This poses a knowledge gap, ranging from conception to the design phase, that this research aims to answer.

Integration of the value chain has several benefits such as increased (quality) control, visibility, stronger relationships, continuous improvement in the modular design etc., which overall contributes to a seamless flow of the network of involved participants (Wuni & Shen, 2021) (van der Ham & Opdenakker, 2021). To establish a vertically integrated value chain, where, among others, developers, architects and manufactures work in optimal synergy to create value in the end project, one must be aware of how to establish collaboration between parties.

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Research Context

2. Research Context

This chapter presents an overview of the research project's context, including how it aims to address the problem definition and research gap identified in the previous chapter. The chapter discusses the research goals, scope, main and sub-research questions, as well as the scientific and social relevance of the study.

2.1 Research goal

When the production process is highly repetitive, it allows for greater standardization and simplification of the design, engineering, and manufacturing processes. This could affect the collaboration and integration among the different members of the value chain, as everyone is working from the same standardized specifications and processes.

The goal, while carrying out this study, is to seek to improve the modular construction process' productivity and efficiency by delivering insights with practical recommendations on creating synergy between developers, architects and manufactures in a vertically-integrated value chain. Additionally, an understanding of different production systems is of the essence to understanding their influence on the cross-functional relationships. The goal of this research is to examine the feasibility of integrating the value chain in modular construction projects, by either validating or refuting claims about such integration and understanding the challenges or success factors for implementing it in practice.

2.2 Scope

The scope of this research can be demarcated by what it will and what it will not cover. The scope will include:

- Modular buildings, build with 3D (prefinished and prefabricated) and 2D construction
- Apartment complexes, a minimum of two stories.
- Residential real estate domain
- Focus on the phase with the highest degree of interdependencies/collaborations between the involved parties (SO till TO): developers, architects, engineers and manufacturers
- Preferred constructions projects built with timber/bio-based[1] material
- Information and data gathering from the EU, Asia and USA
- Case studies and interviewees were limited to the EU and USA

This scope will not include:

- Procurement or contracting
- External relations or factors influencing the integrated development value chain: municipalities, urban planning, certification bodies, clients
- Contractor and sub-contractors
- Advisory groups

[1] Ecologically generated, collected, utilized, and repurposed building materials derived from animal matter or from fungus, plants, or microorganisms. This term is consistent with the City Deal Circular and Conceptual Building Definitions.

2.3 Research Questions

To realize the above-mentioned objective for this research, the following main question is formulated:

1. spo

Next, the literature review substantiating the answers will lead into the next phase of the study, which is Phase 2. This phase will apply the insights and learnings as the basis to develop focus-points which will help the industry experts successfully improve alignment and co-operation during the integrated modularization process, maximizing its benefits: creating synergy. Eventually, this will help accelerate the industrializing of modularity.

2.4 Scientific & social relevance

James T. O'Connor's research "Critical Success Factors and Enables for Optimum and Maximum Industrial Modularization" explores how modularization can optimize the development process of residential real estate with a focus on achieving carbon zero rates using CSF. The study highlights the benefits of modularization, including the ability to construct buildings with zero carbon emissions when using timber materials and the potential to address the housing crisis through faster construction without compromising on quality. O'Connor's research emphasizes the importance of understanding CSFs and their role in increasing the success potential of industrial modular projects. The research also focuses on the industrial sector rather than the building sector, noting the differences in terminology and processes.

Other studies by McKinsey & Company, led by Nick Bertham (2019), Ribeirinho et al.(2020), among others, also provide insights on how to implement a modular construction strategy, including steps to involve all parties in the process and shifts that can lead to an industrialization of the modular construction industry.

This implementation strategy idea of modularization comes from an extensive research team at McKinsey & Company, led by Nick Bertham. The team has laid down the plan for real estate developers to step into the alternative building process (Bertham, Mischke, et al., 2019). Bertham also elaborated on how to include the other involved parties during the process. Another McKinsey & Company research led by Ribeirinho et al. (2020) put more emphasis on which industry shifts will lead to disrupting the modular construction space to a more industrial scale. The paper listed nine different shifts validated by industry experts. Gaining control through value chain integration and moving towards a project to a product-based approach are two of them. Research on them is relevant for scientific and social reasons.

Scientific relevance

- The integration of value chains is a topic that is not well understood in the modular construction industry, as it involves coordinating and integrating multiple players, departments and processes. This research aims to fill this gap by focusing on understanding the challenges and successes of integrating value chains in modular construction.
- This research also contributes to the broader academic discussion on the integration of value chains in the context of product-driven industries, such as car manufacturing, shipbuilding industry and aircraft manufacturing.
- It can also serve as a reference case for future studies that would like to approach similar topics.

Social relevance

- The modular construction industry is growing rapidly as it presents an opportunity to increase efficiency, reduce costs and waste, and improve the quality of the built environment. Furthermore, real-estate developers are considered a natural catalyst for scaling modular construction. Developers must start by rethinking their product strategy to enable modular design. They can determine how their projects are realized and by whom. Developers could collaborate with designers to establish their own unique sets of product offerings. However, this growth is also accompanied by many challenges, one of which is the coordination and management of the supply chain.

- This research can provide valuable insights for practitioners in the modular construction industry, such as developers, architects, engineers, and manufacturers, as it can help them to better understand the complexities and benefits of integrating value chains in their projects. This can help them to improve the efficiency, quality and overall success of their projects.

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3

Methodology

3. Methodology

The purpose of this research is to explore and define the suitable production system for a vertically integrated value chain, as well as how to improve the interconnectivity among the participating internal developing parties. Thereto, it is necessary to understand the various factors leading to such success. The main research question is formulated as:

"How do project- and product-based disciplines within the residential modular construction industry achieve effective vertical value chain integration during the development phase?"

To completely address the main research issue as indicated previously, an appropriate research design with corresponding relevant methodology is required. This chapter outlines the decisions taken and substantiates their implementation in accordance with the project's goal. Initially, the main research question will be answered through a series of sub-questions and methods. This process is described below.

3.1 Research Design

This research can be categorized as a practice-oriented study. Practice-oriented research aims at solving an identified practical problem which needs a deep dive into knowledge and information to contribute to successful innovation. This innovation can also be labelled as an intervention in order to change an existing situation (Verschuren et al., 2010). In this case, the objective is to validate the success of cross-functional integration of the value chain in comparison to the traditional fragmented construction process.

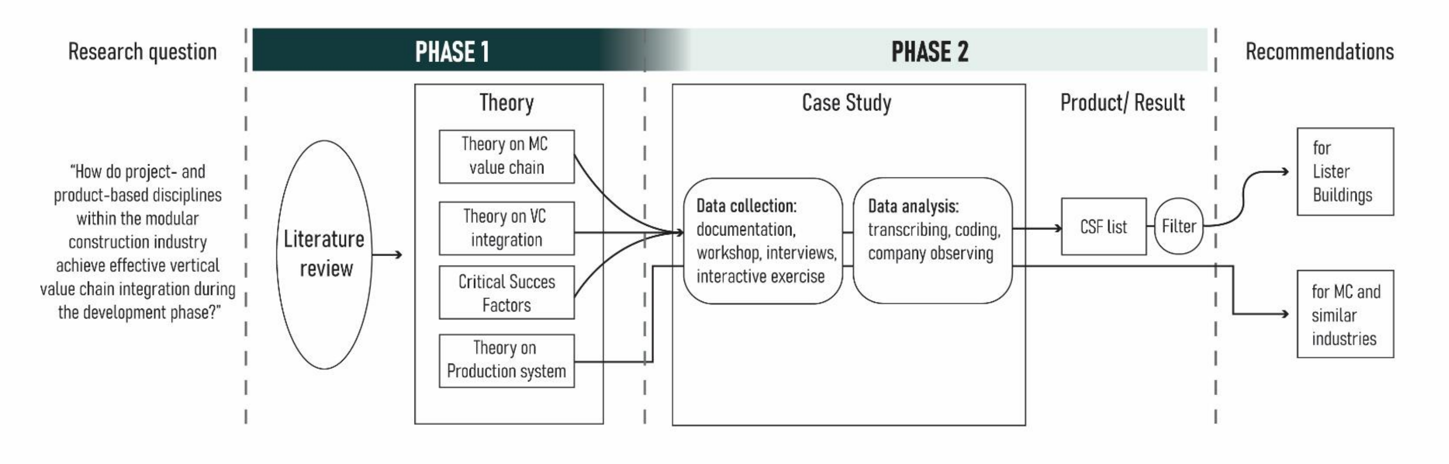
Verschuren et al. (2010) developed a so-called intervention cycle which exists of five stages of research: Problem analysis, diagnosis, design, intervention/change and evaluation. This can be done in series to structure the research towards a successful intervention or as distinct forms of investigation. This research is classified as design-research (Verschuren et al., 2010).

The research is divided into two phases. **Phase 1** will include the literature research to gather knowledge such as the current understanding of modular construction, the different production systems stemming from the manufacturing industry, a deep dive into integrated value chains and the critical factors which steer towards cohesive organizational integration. In addition, exploration is necessary to define terms, benefits and strains of traditional versus modular construction and standardization.

Phase 2 will apply the insights and foundation to develop a list of factors which will help the industry experts successfully improve alignment and integration throughout the value chain; maximizing its benefits during the modular construction process. Through a case study with an integrated modular construction company the gathered, previously establishes, factors will be used as a comparing and analysing tool to gain a better understanding of the experiences operating in such an environment. Eventually, this will help accelerate the industrializing of modularity (Viana et al., 2017). Both phases are elaborated on in the chapters below.

3.2 Phase 1 – Analytical framework

Phase 1 is dedicated to building the body of the analytical framework. This consists of a *Literature Review* on the topics of Modular Construction, Production Systems and Value Chain Integration and the development of the *Conceptual Framework* which consists of a CSF-list to enable integration and the Production System framework. These two tools will be used to structure the experts' review during the case study.



3.2.1 Literature review

To gain a better understanding of value chain integration in the modular construction industry, a considerable review must be conducted of relevant scientific papers. These have to include a thorough study of modular construction, their distinctive differences to traditional construction, processes, value chain structure, which actors are involved during the project and the factors which improve and foster cross-functional integration. The distinctions are of importance to this paper as they could convey the bottleneck or the possible solution to being able to industrialize or improve the modular construction process. The first phase consists of two parts: gaining a thorough understanding of the different elements of interaction during the integration of modular construction projects and the exploration of factors that are considered critical to sustaining and fostering integration between the elements and parties. The methodology and goal are elaborated on below.

- **Modular Construction**

One of the ways to contribute to an improved sustainable and circular solution to the building process is by developing with standardized elements and considering alternative building materials. Before the research goes into depth with these aspects to improve the process, exploration is necessary to define terms, benefits and strains, and the distinguishing differences between the traditional versus modular construction of the value chains. Also, the industrializing shifts within the sector are elaborated to

- **Production Systems**

In recent years there has been more interest in the beneficial aspects of vertically integrating value chains to gain more control. This is not a new concept overall, as other industries have been disrupted from a project-based approach to a product-based approach, meaning also vertically consolidating the production process. How the production system adapts in relation to the rate of standardization of the product, has influence on the value chain. This caused industries such as the car and shipbuilding industry to change their approach and incorporate a high degree of automation. The modular construction industry is just not there yet, therefore it is important to explore the different production systems and establish which will fit the modular production strategy, to understand the level of integration necessary in the value chain.

- **Value Chain Integration**

Creating in between teams when the value chain is vertically integrated is of importance as they not only support one another, they also achieve a reduction in time and cost ultimately leading to higher productivity. This long-term commitment requires working together to produce gained value. At its foundation, integration is about assisting participants in efficiently connecting, communicating, and collaborating. Before developing a focus-plan to achieve efficient integration across the value chain, one must first learn how to establish an environment in which this may flourish. A thorough analysis into critical factors within the vertically-integrated modular construction industry literature will be acquired and categorized in a library.

3.2.2 Conceptual framework – Defining

The conceptual framework exists for the development of two potential tools to assess the level of integration of MC cross-functional departments. This methodology is based on the critical success factor management tool of Rockart (1979, p. 45-60), see figure 6, where factors are used to identify and prioritize the key areas that are crucial for the success of a project or organization.

Rockhart (1979) "Critical Success Factors" tool:

1. ***Identify*** *the* ***key areas*** *that are critical to the success of the project or organization. These key areas are also called CSFs.*
2. ***Prioritize*** *the CSFs based on their importance to the success of the project or organization.*
3. ***Develop a plan*** *to achieve the CSFs. This plan should include specific actions, timelines, and milestones.*
4. ***Monitor and measure*** *the progress of the plan and make adjustments as needed.*
5. ***Continuously evaluate*** *the CSFs and make changes as necessary to ensure that they remain relevant and aligned with the organization's goals.*

Figure 6. Critical Success Factors management method (Rockhart, 1979)

Rockhart's tool is used as inspiration to identify the success factors to enable and improve the integration of MC value chains. In Phase 1, a preliminary CSF list is developed through a series of steps:

1. *Exploration of key areas that are critical to the success of* ***the project/organization***

Conduct a thorough search for scientific papers using relevant but relatively general keywords and similar definitions to those. Search for papers and relevant journals that focus specifically on the research topic, as well as those that discuss the CSFs in a more general sense. This step creates an extensive list of the relevant papers with their CSFs.

2. *Create* ***categories****, filter and consolidate list.*

Once the list of relevant papers with CSFs is collected, organize them into different categories based on the topics they cover. Review the papers in each category and filter out any that are not relevant or do not provide valuable information. Consolidate any duplicated information or similar concepts under one or a new CSF.

3. *Create the* ***preliminary list****.*

Review the final list of CSFs and make sure that the information is clear and easy to understand. Organize the information logically and coherently, and remove any unnecessary details.

By following these steps, you can create a clear and comprehensive overview of the critical success factors based on literature review. Part 2, is assessed after the interviews have been conducted. This will be explained in the following chapter of Phase 2.

3.3 Phase 2 – Case study

The study aims to examine the factors that contribute to the successful integration of the value chain in modular construction projects. To achieve this, an in-depth case study will be conducted on an integrated modular and circular construction company. The methodology includes conducting semi-structured interviews with key players in the company and using interactive exercises to gain a comprehensive understanding of their experiences, challenges, and perceptions of integration within the company. The data collected will then be analysed using a preliminary critical success factor list, which is established based on previous research in the field, to identify key areas for improvement. In **Phase 2**, the focus will be on identifying specific areas to improve integration based on the prioritization of the critical success factors, the assessment of the production system, and the analysis of the interview data. This will help to create a holistic view of the impact that value chain integration has on the efficiency and productivity of the company and allow to determine the focus area to foster integration.

3.3.1 Company profile

For this study, Lister Buildings has been selected as the company profile to investigate the feasibility of integrated modular construction value chains. Lister Buildings is a real estate life cycle platform that specializes in the development, design, engineering, and manufacturing of modular wooden residential buildings. Their core focus is on sustainability, with a specific emphasis on mitigating climate change, addressing resource scarcity, and promoting human health in the built environment. They maintain a production facility in Weert where they manufacture the modules for their buildings, which is a key aspect of their value chain. The internal setup consists of developers, architects, system engineers and manufacturers working together to design and develop modular residential buildings that meet the highest standards of sustainability and quality. Each member of the team brings a unique set of skills and expertise to the project, and they work collaboratively throughout the entire value chain to ensure a smooth and efficient production process. As a result, Lister Buildings represents an ideal company profile to explore the potential for cohesive organizational integration in semi-vertically integrated value chains during the development phase of residential modular construction projects.

3.3.2 Expert interview

The interview is separated into two activities, a semi-unstructured *interview* to gain their experiences, ideas and bottlenecks on a personal and departmental level and *interactive exercises* to visualize the interconnectivity and coordination between the departments from their point of view.

Interview

Through the *CSF Interviews* with experts (developing managers, architects, engineers and manufacturers - a minimum of three per category), the preliminary list of critical success factors may be verified and expanded. This chapter there will be made use of abbreviations for the different departments: Lister Development [LD], Lister Architecture [LA], Lister Systeemontwikkeling [LO] and Lister Manufacturing [LM]. The departments are elaborated on in Chapter 7. Also, a disclaimer is necessary that this part relies on data gathered from the qualitative interviews with humans which can create deviating results. The participant index is shown below. To ensure the privacy and security of participants, the specific details of the participants involved in the study will not be publicly disclosed. The interview activity aims to explore and prioritize the key factors, based on the rate of occurrence and ratio of importance, to enable the successful integration of the value chain in modular construction projects. Data collection was carried out **using semi-structured interviews with participants**, and the questions were designed to elicit information on their experiences, benefits, and challenges related to value chain integration in modular construction projects. However, the questions provided a general outline for the interview but allowed for flexibility to explore specific topics in more depth as the conversation progressed. The interview will cover three topics: personal level, system integration (focused on collaboration) and system design (focused on coordination), the interview protocol and questionnaire are to be found in APPENDIX A.

Table 1. Interview participants

Department	Experience	Product/Project	Date interview
LD	5 – 10	Project	12/12/22
LD	5 – 10	Project	5/12/22
LD	0 – 5	Project	6/12/22
LA	5 – 10	Project	7/11/22
LA	0 – 5	Project	2/12/22
LA	0 – 5	Project	7/11/22
LO	10+	Project/Product	5/12/22
LO	10+	Project/Product	12/12/22
LM	15+	Product	13/12/22
LM	15+	Project/Product	13/12/22
LM	0 – 5	Project	08/12/22

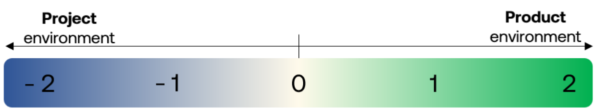
Interactive exercises

There were two exercises. **The first** exercise is to gather information regarding their Production System. This exercise consists of two parts: a questionnaire that asks participants to identify the characteristics of the company's current production system, and a second questionnaire that asks participants to identify the characteristics of the company's desired future production system.

The questionnaire presents the participants with a list of categories, such as design type, strategy, and client input, and asks them to rate the company's current and future production system on a scale of -2 to 2. The categories are aligned with two extremes of production systems: Concept-to-order (CTO) and Make-to-stock (MTS). CTO is a project-related domain, while MTS is a product-related domain (see Appendix B). In the summary of the production systems, there is a flow to be recognized; the residing production systems range sequentially categorically from one extreme to the other. The participants are not aware that the categories correspond to production system terms, and this is done to avoid any potential biases or confusion. After the questionnaires are collected, the responses are analysed and compared at the company and department levels to gain an overall understanding of the collective views and aspirations of the organization for the future.

Table 2. Interview questionnaire: Production System-profile

Characteristic	**Design**	**-2**	**-1**	**0**	**1**	**2**	**Make**
Client input	Greatest degree of input						No input
Project teams	Short term						Long term
..	..						..



Lastly, to gain a better understanding of the company's coordination and collaboration structure, the participants will be asked to provide information about their experience working within the company. The participants will be presented with a graphic overview of the current development process, the format of which can be found in Appendix A. They will be asked to rank the four departments from 1 to 4 (1 being the most and 4 being the least) in terms of which one is "the most essential" at each phase and which one carries "the biggest responsibility" during that phase. The answers from the interviews will then be analysed, processed, and visualized to gain a better understanding of the company's coordination and collaboration structure.

3.3.3 Conceptual framework – Analysing

This study aims to further develop the conceptual framework by analysing the collected data to refine and finalize the critical success factor (CSF) list. This will be done by following a set of established steps to ensure a thorough examination of the data and its relationship to the CSF list.

4. Transcribe and code semi-unstructured interviews with CSF-list

The information gathered from the interviews will be transcribed and coded using the critical success factors (CSF) list established in the literature review. The coding sessions will involve verifying or invalidating the current list, while also keeping an open mind to new CSFs that may have emerged from the data. The goal is to analyse the content to discover interesting nuggets of information: information that is repeated and resembles or contradicts an existing CSF. Any data that do not fit into the existing list but are frequently mentioned and seem relevant to enabling integration will be set aside for further examination and analysis.

The two interactive exercises were in different forms to provide consistent and comparable answers, and to be able to present them in a clear and easy-to-analyse format. The first is a visual presentation of their process and organization, displaying the four departments per phase of the process between SO and TO to gather information on coordination and collaboration links between the different parties involved in a modular construction project. The second exercise was a "current" (LB1.0) and "future" (LB2.0) table with different production system characteristics on product, production and organization levels, to gain a comparative view of the Production System profiles. Again, these are to be viewed in Appendix B.

5. Analyze coded text categorically per CSF

Review the coded text and identify interesting quotes, the rates of occurrence, and the ratio of importance for each CSF. This will help you gain insights into how important each factor is to the success of the modular construction project, and how frequently it is mentioned during the interview. It is also important to review the factors that were not mentioned during the interview and consider eliminating them from the list if they are not relevant to the research. Additionally, it may be useful to review any data that did not fit into the initial CSF list in order to identify any new factors that may have emerged.

6. Validate, invalidate, and/or expand the CSF-list:

The final step in the analysis process is to use the data collected and analyzed, in the previous steps, to refine and improve the list of CSFs identified in the literature review. This step will involve validating, invalidating, and/or expanding the initial list of CSFs to ensure that it accurately reflects the most important factors for success in the modular construction industry. By examining the rate of occurrence and ratio of importance of each CSF, a hierarchical list can be created, which will be used to prioritize the most critical factors for further examination. This research can provide valuable insights for practitioners in the modular construction industry to better understand focus areas when integrating value chains in their projects. Therefore, the end-product will cover final conclusions and recommendations for modular construction and similar product-based industries to gain awareness of the bottlenecks and focus-points to be able to scale towards industrialization.

PHASE 1

LITERATURE REVIEW

Source: Lister

4

Modular Construction

4. Modular Construction

Modular construction has gained significant attention in recent years as an alternative method for building high-quality, sustainable, and cost-effective buildings. This chapter will provide an overview of modular construction, including the key terms and definitions used within the industry, the benefits and impediments of using modular construction, industrial shifts within the modular construction industry, and the value system involved in the process. Each of these topics will be explored in depth in the following subchapters.

4.1 Introduction

One way to speed up the building process is by building with standardized measures and elements, called modules. Modular buildings consist of standardized structural components which are made in an offsite facility and then assembled on-site. The complexity of the pieces being combined determines the complexity of these systems. Single parts that are clipped together using conventional connections and interfaces are the most basic (Bertham, Fuchs, et al., 2019). Modularization is not a new concept; it has been used several times in the past, extensively discussed, and described in numerous ways by different sectors in the construction industry. “Offsite construction” (OSC), “prefabrication”, and “modular construction” (MC), prefabricated housing production (PHP) are all terms that are used interchangeably to describe a variety of approaches and systems but ultimately mean the same thing: dividing a product/project/building into standardized parts, whilst shifting as many activities of the building process to a safely manageable offsite, manufacturing-style production facility (van der Ham & Opdenakker, 2021).

Tatum et al. (1986) pioneered modular systems in both industrial and building construction by exploring a way to improve constructability in the construction sector by using prefabrication, preassembly, and modularization. Their findings indicated that defining the project based on the best applicable building techniques could be critical in the outlook, meaning that some projects could benefit from other building methods, such as prefabrication and assembly. Since their highly innovative work on modularization, a decision-making support framework was developed by Murtaza et al. (1993) to assist construction owners and engineers whether or not to choose the modular construction technique when building a petrochemical/power plant. When the tendency became apparent, Haas et al. (2000) conducted a trends-growth study to determine the effects of prefabrication and preassembly on the industrial construction workforce.

4.2 Terms

The term "modularity" has different meanings depending on the context and the source. In construction, for example, it can refer to the use of sets of units that can be arranged or joined in a variety of ways (Gershenson et al., 2003). It can also refer to the pre-construction of a complete system away from the job site, which is then transported to the site and assembled (Haas et al., 2000). In both cases, the idea is to simplify the process of building and make it more efficient. In general, modularity can be seen as a way to balance the conflicting demands of standardization and customization, allowing for a broad variety of products to be produced by combining a limited number of modules, (Miller & Elgård, 1998).

In other fields, such as product design, the definition of modularity has evolved to include the idea of breaking down complex systems into simpler components that can be easily assembled and disassembled, as in "Contributions of modularity to the circular economy: A systematic review of the literature" Machado & Morioka (2021). This can help extend the life of a product and make it more adaptable to changing needs.

In conclusion, the definition of "modularity" used in this paper, as presented in Machado & Morioka (2021), aligns best with the focus and objectives of this paper as it includes the idea of modularity as a design approach that improves the product lifecycle, reduces dependency on the job site, and balances the conflicting demands of standardization and customization.

4.3 Degrees of Standardizations

In the construction industry, standardization refers to the degree to which building components and systems are pre-manufactured and pre-assembled in a controlled factory environment before being transported to the construction site for installation(Gibb & Isack, 2001). The level of standardization can be classified into several categories:

- Component subassembly: Small-scale elements, such as windows, are manufactured and assembled in a factory environment.
- Non-volumetric preassembly: Items are manufactured and assembled in a factory environment to form non-volumetric units, such as walls, which are then transported to the construction site for installation.
- Volumetric preassembly: Similar to the previous level, items are manufactured and assembled in a factory environment to form volumetric units, such as bathrooms, which enclose usable space and are fully finished internally before being transported to the construction site for installation.
- Complete (modular) construction: Fully finished modules, including entire buildings, are manufactured and assembled in a factory environment and transported to the construction site for installation. (Bertram et al., 2019; Pan & Hon, 2020)

In Hong Kong and Singapore, the government encourages the use of modular construction, called MiC in Hong Kong and PPVC in Singapore, to increase productivity and reduce construction time and labour-intensive activities. These are considered the ultimate form of modularization, as it involves prefabricating 75-90% of the construction work in a controlled off-site facility and does not limit to one single module as a home, which most volumetric design are (Pan & Hon, 2020). However, there are limitations to the use of prefabricated and precast components, such as technical issues and ineffective assembly management. Therefore, it is important to consider the performance, technology systems, challenges, and lessons learned when implementing modular construction methods in a project. Additionally, for sustainable construction, it is important to consider the economic, environmental, and social dimensions of modular buildings during performance evaluations.(Liu et al., 2019; Xu et al., 2020)

Modular construction can also be classified based on modular assembly classifications:

- 1D modular construction: Modules are primarily built with a standardized width and length, but with variable heights. This method is mostly used in the construction of high-rise buildings.
- 2D modular construction: Modules are standardized in width, length and height. This method is mostly used in the construction of mid-rise buildings.
- 3D modular construction: Modules are standardized in all three dimensions, including width, length, and height. This method is mostly used in the construction of mid-rise to low-rise buildings.
- Hybrid modular construction: This method combines traditional construction techniques with modular construction techniques. It uses modules as a starting point but allows for customized and site-specific designs. (Kamali & Hewage, 2016)

It is important to note that these classifications are not mutually exclusive and that a modular construction project can incorporate elements from multiple classifications.

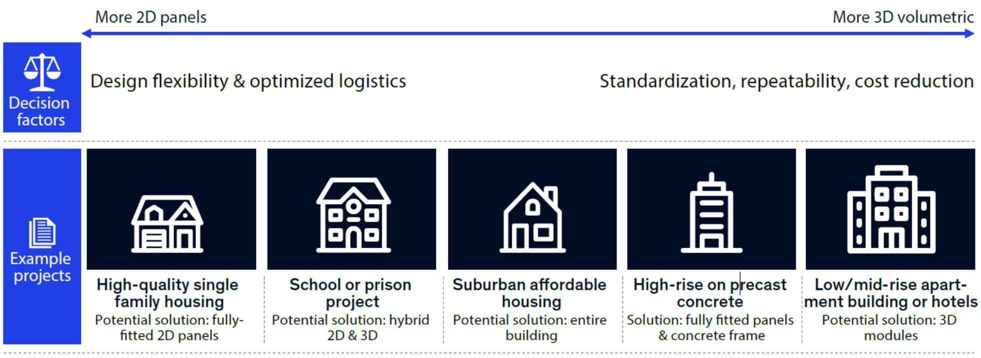


Figure 7. Level of standardization in modular construction (Bertram et al., 2019)

4.4 Benefits

Schools, prisons, hotels, student housing, residential apartment complexes, and similar projects appear to be particularly suitable to modular building systems due to their inherent repetition, homogeneity in design, and hence having a more predictable building process. (van der Ham & Opdenakker, 2021). It offers significant benefits over traditional onsite construction and can accommodate to a solution for the rapid urbanization and housing shortage, whilst also covering the sustainability aims when choosing materials such as timber. Numerous studies on modularization have been conducted by various researchers. O'Connor et al. (2014) recently found 21 CSFs for modularization and enablers for success factors, as well as the association between modularization CSFs and project performance. Choi (2014) elaborates on the benefits and impediments of using the modular building method in his dissertation. However, because this paper was released in 2014, making it is slightly out of date. In the meantime, several studies have been followed up with a quantifiable approach substantiating the previously qualitative experiences and knowledge. During the literature review, this table is updated and expanded to include literature up to 2022.

Table 3. Literature overview - Benefits of modular construction.

#	Benefits	Literature
	Reduced Production costs	Fagerlund 2001; Gotlieb et al. 2001; Jameson 2007; Lapp and Golay 1997; Post 2010; Rogan et al. 2000; (J. O. Choi et al., 2019), (Tsz Wai et al., 2021) (Bertham, Fuchs, et al., 2019) (R. Lawson & Ogden, 2010);
	Improved Scheduled Performance	CII 1987; CII 2002; CII 2011; Burke and Miller 1998; Gibb 1999; Gotlieb et al. 2001; Jameson 2007; Judy 2012; Lapp and Golay 1997; MBI 2010; McGraw-Hill 2001; Post 2010; Rogan et al. 2000; SCS_Energy 2006; Williams 2011; (J. O. Choi et al., 2019), (Tsz Wai et al., 2021), (Bertham, Fuchs, et al., 2019)
	Improved Predictability	(van der Ham & Opdenakker, 2021), (Tsz Wai et al., 2021)
	Increased Productivity	Jameson 2007; Jergeas 2010; McGraw-Hill 2011; Murtaza et al. 1993; Rogan et al. 2000; SCS_Energy 2006; (J. O. Choi et al., 2019), (van der Ham & Opdenakker, 2021), (Tsz Wai et al., 2021)
	Higher Overall Quality	Judy 2012; Lapp and Golay 1997; SCS_Energy 2006; (Al-Hussein et al., 2009) (van der Ham & Opdenakker, 2021), (Tsz Wai et al., 2021); (Bertham, Fuchs, et al., 2019; Lee et al., 2020)
	Increased Safety Performance	CII 2002; Court et al. 2009; Jameson 2007; Judy 2012; MBI 2010; SCS_Energy 2006 ; (J. O. Choi et al., 2019), (van der Ham & Opdenakker, 2021), (Tsz Wai et al., 2021)
	Reduced Waste and Better Environmental Performance	KBR 2009; MBI 2010; Tam et al. 2007;(R. Lawson & Ogden, 2010) (J. O. Choi et al., 2019), (Wuni & Shen, 2022), (van der Ham & Opdenakker, 2021), (Tsz Wai et al., 2021)
	a. Reduced noise	(J. O. Choi et al., 2019), (van der Ham & Opdenakker, 2021)
	Reduced Site-based Permits	Jameson 2007; SCS_Energy 2006
	Improved site operations	(J. O. Choi et al., 2019) (Wuni & Shen, 2022)

4.4.1 Production costs

There are various reasons to choose modularization in construction. Lowering costs is one of the primary advantages of why industry leaders are using this approach. The overall reduction of the costs stems from different areas of the project. First of all, the shift of labour location from on-site to off-site helps reduce the overall labour costs (Kamali & Hewage, 2016), the on-site accommodation costs (Fagerlund, 2001) (Gotlieb et al. 2001) and reduced maintenance costs due to improved structure quality (Al-Hussein et al., 2009). Furthermore, the reduction in re-design also takes a huge toll on the overall budget when there are deficits in the design. However, the costs of the initial design, material sourcing, off-site labour, logistics and factory costs are still expenses which need to be considered and are on the other side also demanding of the budget. Nevertheless, given these trade-offs, the projects with the highest share of labour-intensive tasks and the highest levels of repeatability are most likely to yield the biggest cost reductions. Overall, depending on the level of standardization, in comparison to traditional construction, the costs are reduced between 20-65% (Bertham, Fuchs, et al., 2019) or depending on the size of the project specified by another scientific paper between 40 (small) – 63 (big)% (Hammad et al., 2019).

4.4.2 Schedule

The construction industry has been notorious when it comes down to delays in the schedule or cost overruns. Previous studies such as (Gotlieb et al. 2001; Jameson 2007; Judy 2012; Lapp and Golay 1997; MBI 2010; McGraw-Hill 2011; Post 2010; Rogan et al. 2000; SCS_Energy 2006) presented a reduction in construction time and overall planning. Due to the off-site construction technique, the workforce is able to continue their work in a controlled conditioned environment which boosts productivity (J. O. Choi et al., 2019). Resulting in better time control and site operation of the facility and project. Studies have shown that MC implementation can lead to time-saving (NIBS, 2018). In a time-saving analysis of projects in the UK, Singapore, USA and Asia the percentage change in construction time ranged from 6% - 40%. The lowest change was due to having limited experience with modular systems. Nevertheless, even without experience, there is still improvement in scheduling. (Tsz Wai et al., 2021). Overall, due to the parallel activities enabled by off-site manufacturing, the biggest cuts are achieved during the planning and design (when the designs have been repeated) and the on-site installation. Reaching planning shortenings from 20 – 50%. (Bertham, Fuchs, et al., 2019)

4.4.3 Quality

Quality is also another key element when developing buildings. Due to several parameters in modular construction, there is a better outlook and guarantee of the quality of the end-product. Firstly, the indoor environment helps to control the temperature and moisture and keeps the dynamic weather conditions outdoors (Tsz Wai et al., 2021). Moving construction operations into a confined, shielded, and carefully regulated area where closer inspection is feasible would immediately enhance the quality of the modules being built. Precision will be improved even further by automated systems. (Bertham, Fuchs, et al., 2019). Also, due to being able to have different disciplines working parallel on-site (indoor) creates an environment where the teams can work interdisciplinary. Meaning knowledge and expertise are on hand to solve complex issues at once. Resulting in less rework afterwards and improving the quality of the product. Finally, the proportion of rework in off-site manufacturing is substantially smaller than in traditional construction due to module and BIM control checks at various stages, which also validate quality. (Lee et al., 2020). Because of the high level of quality control allowed, modular and panelized construction is tighter and stronger than stick-built or conventional methods. (Al-Hussein et al., 2009)

4.4.4 Safety

Safety, security and health of the workforce should be one of the main concerns of the superior. When working in the construction sector, there is always a small risk to take into account. From 2019 to 2020, there was a 31% rise in events involving casualties in the Dutch construction industry. The majority of accidents (29%) occurred when operating at a height (Cobouw, 2021). As a result, relocating offshore work to a controlled setting decreases total safety hazards dramatically. The manufacturing faculty is more suited to safe material handling and assembly than traditional methods. When the demand to work on high platforms or against walls, for example, is removed, safety issues are considerably minimized. (CII 2002; Court et al. 2009; Jameson 2007; Judy 2012; MBI 2010; Al-Hussein et al., 2009). Additionally, with fewer people necessary on the construction site during assembly reduces the likelihood of casualties, such as accidents involving falling equipment (Tsz Wai et al., 2021). All in all, the modular construction method reduces safety incidents by up to 80% (Lawson et al., 2012).

4.4.5 Sustainability

Lawson & Ogden (2010) estimated that modular construction projects produced at least 15% less construction material waste than traditional construction projects. One of the characteristics contributing to the decrease in waste is the ability of the module to re-locate and reuse. Modularity also refers to the modules' capacity to be easily assembled and disassembled. When a building or structure requires maintenance or reaches the end of its lifetime, components or the entire structure can be dismantled for repair and re-use (Tsz Wai et al., 2021). Loizou et al. (2021) compared the waste generated from traditional versus modular construction techniques and found a significant reduction in waste weight when the modular technique was used for a project. For small and large structures it was measured up to 81.3% and 83.2%, respectively. Waste materials are minimized, and the waste created during the manufacturing process and assembly is simply repurposed and recycled. Aside from waste, there is also less air and water pollution, a lower total carbon footprint, less dust and noise, and lower overall energy expenses (MBI, 2010). In particular, the adoption of modular construction in a small project and large project led to a 4% and 8% reduction in maximum noise level, 56% and 31% reduction in operational energy use, 53% and 61% reduction in embodied energy when compared to the adoption of conventional construction (Hammad et al., 2019).

4.4.6 Productivity and predictability

With the assurance of increased productivity, increased control over cost and schedule performances with the delivery of better quality homes, as well as the certainty of being able to estimate the materials and labour needed increase the predictability of a project. Predictability is an uncommon industrial phrase, but for forward-thinking businesses, shifting construction from the building site to the factory assembly line creates a less heightened risk of delivering buildings with a high degree of repetition. Furthermore, the quantity of labour-intensive activity performed by the workforce in a controlled environment reduces the danger of injury. All of the previously mentioned elements result in a regaining of control over the total project due to the improved predictability. Extensive research analyzed the actual and expected benefits of modular methods in the USA and Hong Kong. By comparing survey results with comparable studies conducted in the United States, this study vividly emphasized the peculiarities of modular approaches application in dense metropolitan areas. As compared to the US, poll participants chose 'improved site operations' as the most significant benefit. This advantage is a synthesis of the beneficial impacts of modular construction on costs, schedule, safety, quality, and sustainability, which leads, subsequently, to a rise in productivity and increased predictability.

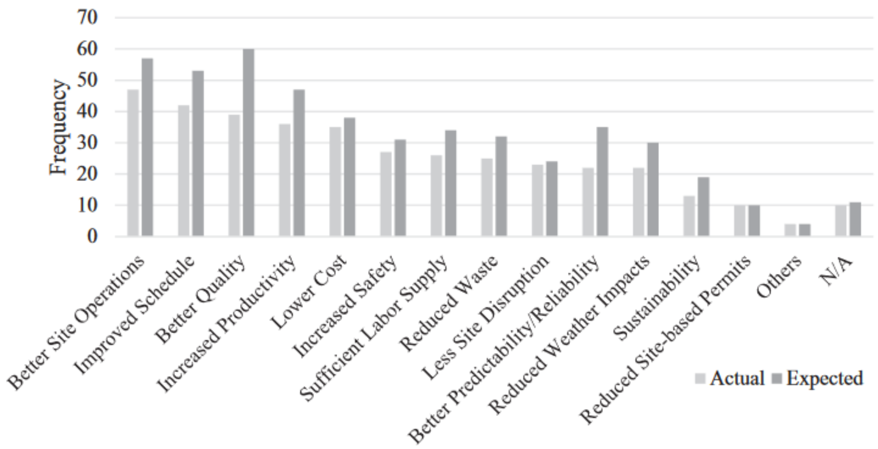


Figure 8. Actual and expected benefits of modular methods (Choi et al., 2019)

4.5 Impediments

Studies have shown the challenges and impediments that come with the implementation and usage of modular construction (J. O. Choi et al., 2019; Ferdous et al., 2019; Tsz Wai et al., 2021; van der Ham & Opdenakker, 2021; Wuni et al., 2021). However, many of the challenges have been the same for the last 20 years. (van der Ham & Opdenakker, 2021) Choi (2014)'s literature review about the impediments of modular construction still aligns with the insights from more recent literature. The literature insights are grouped in the table below to create an overview.

Table 4. Literature overview - Impediments of modular construction.

#	Impediments	Literature
	Start-up cost	Akagi et al. 2002; Lapp and Golay 1997; (Ferdous et al., 2019; Kamali & Hewage, 2016; R. M. Lawson et al., 2012; Rippon, 2011; Zhai et al., 2014)
	Coordination	Fagerlund 2001(Azhar et al., 2013; Hořínková, 2021; Kamali & Hewage, 2016; Rahman, 2014)
	Early Design Freeze	Akagi et al. 2002; Ericsson and Erixon 1999; Fagerlund 2001; Lapp and Golay 1997 (J. O. Choi, 2014; Rahman, 2014)
	Logistics	(Ferdous et al., 2019; Hořínková, 2021; Kamali & Hewage, 2016; Liu et al., 2019; Tsz Wai et al., 2021)
	Competency	Akagi et al. 2002; Deemer 1996; Jameson 2007; Jumbo_Shipping 2008; Youdale 2009; Youdale 2010 (J. O. Choi, 2014; Hořínková, 2021; Kamali & Hewage, 2016; Rahman, 2014)

4.5.1 Start-up cost

First, starting off in this business is not cheap. Many scholars and practitioners believe that economic considerations are a critical component of the decision-making process for determining the best building method (Zhai et al., 2014). A high initial investment is required to set up the manufacturing facility where the prefabricated building modules can be assembled (Kamali & Hewage, 2016). China has this listed as the biggest barrier when choosing to invest in the traditional or modular business. The UK construction industry experience this difficulty as well, listing it as one of the main barriers (Ferdous et al., 2019). Certain initial fixed investments are, e.g. placement of manufacturing machinery and factory infrastructure for storage, materials handling and distribution, heating, lighting and running costs of the factory and the instalment of testing/approval systems (R. Lawson & Ogden, 2010). Furthermore, in an ideal circumstance, transportation expenses are small and offset by savings in design errors or on-site labour force; nonetheless, transportation can be an expensive investment when the distribution, permits, and number of trailers are not properly estimated (Bertham, Fuchs, et al., 2019; Rippon, 2011).

4.5.2 Coordination

Comparing the different approaches between traditional and modular construction, the main difference is the construction process. There are many causing this barrier to be one of the most difficult to resolve. First, the traditional construction process has a linear trajectory throughout the project where the project is being handed over from phase to phase. However, with a modular construction process, this is consolidated as some activities are positioned parallel to each other. Because the off-site/prefabrication technique is departing from the traditional construction process, which is based on a project-approach. Modular construction is significantly different and actually will benefit to shift to a product-approach due to the balance of the repetition in design and customizability. (Hořínková, 2021). Due to the fragmented nature of the traditional industry, knowledge is lost when the project is delivered and the teams disintegrate, leading to a cycle of re-inventing the wheel of collaborating and coordinating between the various involved parties (Rahman, 2014).

A study performed by Azhar et al. (2013) ranked through an extensive questionnaire, organizational readiness (e.g. Early involvement of top management, Familiarity with modularization and Integration & collaboration among players) as the major decision-making factor for selecting modular construction over traditional construction. Pre-project planning, procurement, supply chain scheduling, installation and construction, and delivery all require more comprehensive and effective collaboration and coordination. Owners, engineers, designers, suppliers, and contractors must communicate frequently in order to have access to crucial information such as options, designs, transportation requirements, and schedules. (Kamali & Hewage, 2016). Identifying these barriers and challenges matter to be able to search for the most fitting solution, otherwise, it will have negative effects on the quality of the end-product and the overall process.

4.5.3 Early design freeze

Modular building methods may limit the customization options for the overall project design. It is difficult to redesign a building to utilize modules once a design has been established. This approach does not maximize the potential benefits of designing the project with modules from the outset (Choi, 2014). In modular building projects, an early design freeze is necessary to commence the manufacturing of relevant components and modules as early as possible. Any modifications to the design after manufacturing begins can affect how the different components fit together, which may result in inflexibility and unsuitability for late design alterations. To mitigate these issues, significant coordination is required between the design and engineering teams to identify and resolve any risks associated with a later design freeze (Rahman, 2014). In conventional construction, clients usually have the authority to modify the design. However, freezing the design early necessitates adopting a completed design even before module manufacture begins. This issue may be a significant factor that leads clients to prefer traditional building processes over modular processes.

4.5.4 Logistics

After completing the modules, they are ready for transportation to the construction site. It can be concluded that the module dimensions are limited by their transportation possibilities. One needs transportation either by vehicle or, in the case of international travel, by ship. It is important to design the modules' floorplan to be able to fit the maximum dimension of the vehicle. Standard measures for the floorplans are between 6x3m or 9x3m, depending on the vehicle used (Hořínková, 2021). Larger modules are occasionally constructed for projects that require particular oversized transport, which means that extra accompanying vehicles and permits are in place during transportation. This mode of transportation is not without cost (Kamali & Hewage, 2016; Tsz Wai et al., 2021).

The transportation of PMC components must be carefully managed logistically. It is required to choose a route from the facility to the building site that would hinder transit (Liu et al., 2019). For instance, vehicle vibrations during transportation may cause component damage, and the severity of the damage normally rises with the roughness of the road surface (Ferdous et al., 2019). When complications do happen, they lead to overruns in schedule and costs (Bertham, Fuchs, et al., 2019). As a result, the modular building method poses substantial logistical risks.

4.5.5 Competency

The success of any new technique depends on the willingness of innovators and early adopters to try it out and work through the inevitable trials and errors. However, the pool of experts in modular construction is currently small, which has resulted in some projects being led by inexperienced personnel. Furthermore, the limited market demand for modular construction means that there are few opportunities for new people to learn the techniques involved (Rahman, 2014). The implementation and exploitation of the benefits of modular construction require highly skilled personnel, both in factories for manufacturing components and modules and on-site for the accurate assembly of these parts. It is also crucial for this personnel to integrate the different teams to increase productivity and predictability. Without this competency, the potential benefits of modular construction cannot be fully realized (Hořínková, 2021; Kamali & Hewage, 2016).

In addition, clients may not be aware of the procedures and benefits of modular construction, and their lack of knowledge can lead to delays in decision-making, which may undermine the benefits of modular construction (J. O. Choi, 2014; Hořínková, 2021). Therefore, the importance of competency in modular construction cannot be overstated, especially considering the use of project and product-based approaches within the sector.

4.6 Industrial shifts within the modular construction industry

The building sector has been formed over time by a single traditional method. However, this method has yet to lead to a more productive state of innovation. Other techniques of disrupting the entrenched traditional building business have emerged. The modular building approach is one of them. The usage of this technology compelled specialists to reassess and rebuild the traditional building process to make it more compatible with the modular procedure. It is a solid starting move toward modernizing the building process, but the root of the problem is that the entire modular method is not designed to be combined with the existing procedure. As a result, it is critical to continue moving forward toward a better methodology and technique of application.

4.6.1 From project- to product-based

The shift towards modular construction means the limitation of the flexibility spectrum. A project approach is driven by "the golden Triangle"; a model that concludes that the quality of work is bound by the project's time, scope, and cost, regardless of the value produced. The traditional way develops solutions on a project-based approach. It begins its projects with a blank canvas with a few barriers to take into account but design-wise able to deliver a unique outcome. Still, there is a routine to be found in the building process. Undeniably, the delivery of the final project will provide value to the client and the surroundings, however, the project value diminishes with a new (unique) project, when temporary teams separate and the skills learned during the previous project might not be applied to the next (unique) project.

PROJECT MINDSET	PRODUCT MINDSET
Temporary teams	Long-lived teams
Build-once mentality	Test and learn mentality
Customer feedback at the end	Customer feedback throughout the product
Release once	Release continuously
Success is measured by delivery of scope within time and budget	Success is measured by customer satisfaction and value created
Scope is determined by stakeholders	Scope guidelines are set with stakeholders and teams learn through experimentation and customer feedback

Figure 9. Project management vs. Product management (Charak, 2021)

When adopting the modular approach the main difference is building with standardized modules which limit the design flexibility. The modules will be manufactured in a controlled off-site environment where the production normally is set out in a continuous assembly line, comparable with other modular industries such as the car manufactory industry. The modules' component designs need to lend themselves to maintaining a processing line, without the need to continually update the line itself to supply certain specific features (Ribeirinho et al., 2020).

The "building block" (read: module) of a modular residential building forms the core of the design. Therefore, the product should attract the client. In project-based approaches, the client determines the scope, requirements and, if applicable, the design. So the traditional project accommodates a specific need and desire, whereas the modular project attracts the client with their product and capabilities. (Bertham, Fuchs, et al., 2019)

Due to the continuous development curve, the modular building concept benefits from a long-term partnership between permanent partners. With the repeating loop of collaboration between architects, suppliers and manufacturers, one is able to learn from feedback and improve the requirements of the design. The right design can improve productivity by 3–12 per cent (Ribeirinho et al., 2020). The standardized sub-elements and building blocks will most likely be created internally in R&D-like functions (van der Ham & Opdenakker, 2021). The elements will be manufactured separately by vendors and assembled with modification possibilities in the off-site facility to match the specific requirements of each project. Because of the defined metrics and components, the majority of the final project contains a set of variations, making the learning and progress trajectory easier due to repetition.

All of these characteristics form a substantial argument against the use of the project-based approach for modular building projects. The method will benefit more from a product-based approach. Mass adoption of this approach most likely will increase the probability of the use of an industry-wide standard for modules and components. There will most likely be a balance of basic features and components (produced to common, industry-wide standards) and customised, configurable ones (such as exteriors) to meet the demands of individual customers (Bertham, Fuchs, et al., 2019).

4.6.2 Consolidation

Consolidation within the construction industry is becoming more common as companies strive to specialize, innovate and compete at a larger scale. This includes consolidation within specific parts of the value chain and across the entire value chain. Companies are turning to consolidation to gain access to the resources and expertise needed to invest in new technologies, materials and facilities (Bertham, Mischke, et al., 2019). The industry is also moving towards a product-based approach through modular design, libraries of modular elements and components that can be assembled to create customized products according to customer requirements. This approach allows for greater standardization and repeatability, which can help companies achieve economies of scale (Gann, 1996). Prefabrication and use of pre-finished volumetric modules may also become more common to increase efficiency and decrease costs (Bertham, Fuchs, et al., 2019). However, there will still be a need for creativity in designing bespoke products, leading to a more collaborative and dynamic industry where innovation and customization coexist with efficiency and standardization.

4.6.3 Value-chain control by vertical integration

Another critically influential shift that will elevate the modular process to an industrialized level is the limiting of passing on the project in between phases and project participants. Due to this approach, the knowledge gathered in the previous phase will never be perfectly transferred to the other party without involvement. Also, after the completion of the project, the project team disintegrates altogether with the collectively gained knowledge and important insights to be lost (Hyun et al., 2020).

Gaining control over the value chain can increase your advantage against your competition. This gain of advantage stems from the different activities involved during the project, such as designing, producing, marketing and delivering. Combining all the activities within the project or process forms the value chain. Within the modular construction industry developers, architects, engineers, manufacturers and suppliers can play a significant role in creating value for the client. However, close collaboration between the parties is necessary to avoid delays due to, e.g., design errors and rework in the supplied materials before assembly.

Vertical integration along the value chain is common practice in other industries, such as the car, aircraft or ship manufacturing. Those industries changed when Henry Ford introduced a new production method by using an assembly line for the production of the Model T. The motivation for the integration has to do with essential components being manufactured by third-party suppliers. Manufacturers form integrated partnerships for R&D and testing in order to build higher-quality and more efficient components for their own products and therefore gaining a competitive advantage over their competitors. Several attempts have been made to apply this technology from the car manufacturing to the mass manufacturing of affordable housing construction (Gann, 1996).

In recent studies, it has been shown that consolidation of the construction industry through vertical integration of the supply chain or strategic alliances/partnerships can lead to positive results in standardization and integration. Ribeirinho et al. (2020) conclude through an extensive international study that companies will move to own or control important activities along the value chain, such as design and engineering, select-component manufacturing, supply-chain management, and on-site assembly. Bertham, Fuchs, et al. (2019) highlighted that collaboration between engineering, manufacturing, and designing parties can lead to fewer errors during the assembly and construction process. Choi (2014) emphasizes particularly the importance of early collaboration and coordination among stakeholders, industry members, and other involved parties for positive results in standardization and integration.

Examples of companies that have implemented this approach include Katerra, who have integrated their supply chain vertically and horizontally based on the concept of integrating design, manufacturing, and assembly acquisitions on a digital platform (RoboMQ, 2021). One of the key reasons industry executives desire to vertically integrate, particularly in industrialized construction, is to coordinate the supply chain under a single direction (Browne, 2021). However, it's important to note that lack of coordination among and between participants can also lead to negative results such as Katerra's bankruptcy. Experts have argued that this was due to the intense growth and lack of integration and merging between parties, highlighting the importance of coordination, communication, and alignment during the integration process (Baria, 2021; Browne, 2021; RoboMQ, 2021).

4.7 The value system

This chapter elaborates on the differences between the value chain and the supply chain within the value system, and the transition this system is undergoing to be able to coordinate the integration of the modular construction value chain.

4.7.1 Value system: value chain vs. supply chain

The definitions of the value system, the value chain, and the supply chain are often misunderstood, due to the resembling nature of the concepts. Porter (1985) introduces the value system concept as a chain of linked activities performed by an organization that impact its competitiveness by adding value at each step during the activities. A firm has its own value chain but it normally also is embedded in a larger value chain, also known as the value system, as seen in figure 10. Displayed is the entire chain where value is created in each step of the process. Suppliers create upstream value by delivering the requested input to the firm (Porter, 1985).

Figure 10. Single-industry firm's value chains (Porter, 1985)

Due to the eco-systems, they are utilized in, or a project- or product-system, this use of terminology might cause some confusion. Within the project environment, the client satisfaction and their input into the development of the final project play a significant role. Value chains place a strong emphasis on the advantages that benefit customers, the interconnected activities that create value, and the ensuing demand and cash flows. When the customer's requirements and objectives are incorporated into the final result, the value will be created. Hence, the value chain reflects the acquisition and development process of traditional construction projects (Feller et al., 2006). For instance, the procuring client, such as the government, issued a request for a residential building project with a list of requirements. When awarded this contract, the value chain, comprising developers, architects, engineers, contractors, subcontractors, etc., will work together to execute a project that meets the client's specifications, creating value with each step in the value chain.

In the product environment, the value system plays a smaller role. One wants to produce something the customer wants to buy. However, the majority of the product industry focuses on the efficiency of the supply chain: transforming natural resources, raw materials and components into a finished product or service that is delivered to the end customer. One of the most significant distinctions between a supply chain and a value chain is that the systems flow in opposite directions (Porter, 1985; Rachi, 2012).

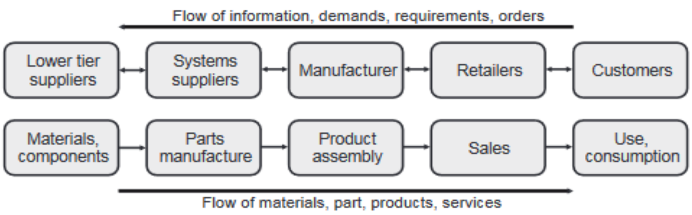


Figure 11. Generic configuration of a supply chain in manufacturing (Vrijhoef & Koskela, 2000)

Vrijhoef & Koskela (2000) made a generic configuration of a product supply chain in the manufacturing industry, where the top outline represents the flow of information, demands, requirements, etc., and the bottom outline depicts the supply flow of the materials throughout the system. Figure 12, shows a re-interpretation of Vrijhoef & Koskela (2000)'s supply chain image (see figure 11) to be able to display the value systems of different industries. It is noticeable that in the product environment the supply chain is mentioned more often and in the project environment the value chain. In modular construction both are used, however, to clear out any confusion when referencing the flow below this paper will use a "value system" to include both.

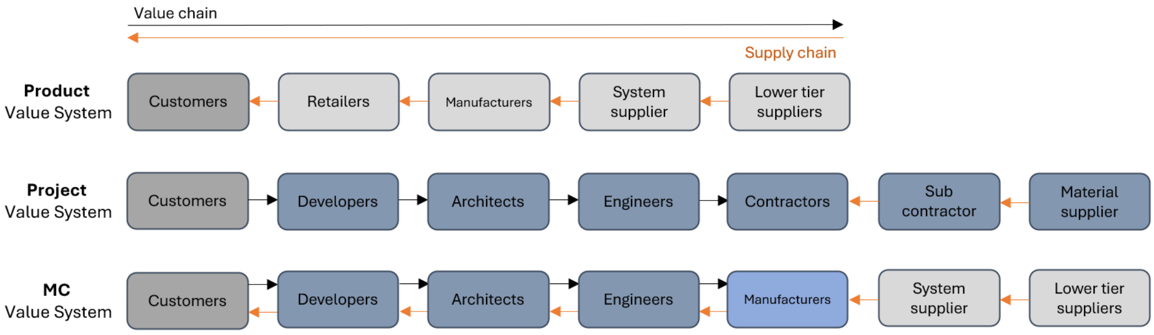


Figure 12. Value system: product, project and modular construction value chains vs supply chains (o.i, 2022)

The distinction between the Product Value System and the Modular Construction (MC) Value System displays the integration of developers, architects and engineers. These actors contribute to the project-based nature of modular construction, allowing for a certain level of design freedom to accommodate the preferences of the client.

4.7.2 The system transition

The paradigm of construction (read: project) as a manufacturing (read: product) process has been elaborated in the traditional construction industry for quite a while, whilst the modular building technique has been steadily gaining traction (Kornelius & Wamelink, 1998). The organization and coordination of the value system have been one of the most notable distinctions between construction and manufacturing due to, respectively, the sector-specific distinctions, such as the one-off, temporal nature of projects or the repetitive, continuous nature of products (Vrijhoef, 2011).

The modular construction supply chain differs from the traditional approach due to the changes in construction location and activities. However, they still use the same project-based approach as traditional construction. Because of this, both still operate in a value system which is highly flexible and fragmented due to the various subsectors (industrial, commercial, residential), disciplines (developers, architects, advisors, investors, engineers, etc.) and external parties to partner or collaborate with. All these different scales, options and elements have led the building industry to deal with high levels of fragmentation within their value system (Vrijhoef, 2011). Nevertheless, within the modular construction value system there is a resemblance to be made with the manufacturing industry, which thrives on a productive characteristic: standardization.

Perspectives	Manufacturing	Construction
Product	Components have a central role in the definition of the product architecture	Buildings combine components and spatial voids, which perform the most important product functions
Process	Suppliers deliver complex modules that are simply assembled by the main manufacturer	Much work is usually performed on site, using traditional technologies
Supply chain	The supply chain gets involved in the design and production of modules for a large number of products	Temporary supply chains usually have limited incentives to produce the same module for a large number of projects

Figure 13. Differences between construction vs manufacturing: product modularity (Rocha et al., 2015)

Rocha et al. (2015) explain the three main differences between the product and project approach: product, process and supply chain. The modular industry might profit by analyzing these three aspects from both the design and manufacturing sides, comparing them, and adapting its own method by combining the two. As a stand-alone unique process that parallels the building and manufacturing processes will enable a more appropriate approach to modular construction.

In hindsight, most systems exist out of the demand and supply system. Vrijhoef & De Ridder (2005) depicted this system around a building object, see the top image in figure 14. The fragmentation of the traditional supply system leads to a significant degree of disconnection between the many phases and operations, which results in the lead to errors, low efficiency and effectiveness, low innovation and a lack of information sharing. As a solution, Deming advocated in his 1981 article that "breaking down barriers between departments", and creating a long-term relationship of loyalty and trust, would resolve the fragmentation while enhancing the quality and lowering the manufacturing costs (Deming, 1981).

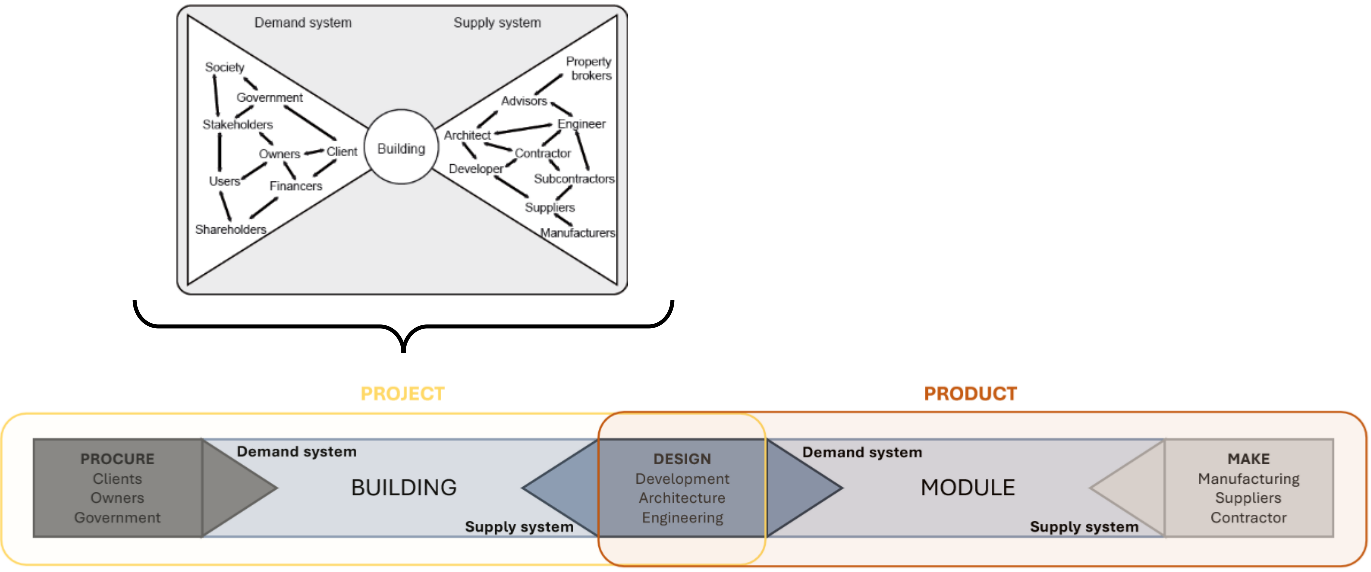


Figure 14. Modular construction value chain: project vs. product. (o.i., 2022)

When inspecting the figure of Vrijhoef & De Ridder (2005), the two systems are depicted as the demanding and supplying side of the project, which is a building. Two changes will happen when the construction project becomes a modular construction project and disciplines are being integrated into one project team or company.

First, the project will split into a project-system, the "building", and a product-system, which is the "module". This causes the second change which is the division of the original supply system into disciplines, covering the upstream design process ("DESIGN") and the downstream production process ("MAKE"). The new display of the modified value system is depicted in figure 14. In a modular construction project, the DESIGN group serves a dual role as a supplier in the project environment and a demander in the product environment.

Using manufacturing as a business strategy towards industrialization could mean adopting product characteristics into traditional project systems. The module in this system is considered the product. When considering the module as a reasonably standardized product, one can employ manufacturing or product-based organizational functions and methods.


Source: Lister

5

Production Systems

5. Production Systems

Production systems are the core of any manufacturing process, and they play a crucial role in the design, planning, and delivery of products. The production system consists of interrelated and interdependent components that are responsible for transforming raw materials into finished goods. The product-production process and product-production system are two important components of the production system, and they are closely related to each other.

5.1 Product and production process

The "production process" specifies the operational objectives and resources required to manufacture the product. In 1984, the first production-process structure was developed and published in the Havard Business Review by Hayes and Wheelwright. Managers were able to assess the best suitable production system based on a mix of the production rate volume and the product demand to determine a given product, see figure 15. Oil refineries use “continuous” processes because of the high volumes of an identical product and the high demand; car assembly lines use “assembly” lines processes because of the intermediate volumes of a similar product; and “job shops” and “project”-type processes are ideal for producing low volumes of high varieties. The latter is a suitable production process for a traditional construction project because of the low volumes due to the low repetition in the project and low demand due to it being a unique, one-of-a-kind project. This approach of aligning products with production processes identifies problems created by using the incorrect method. For instance, using a “continuous” process to produce a one-of-a-kind product, results in substantial out-of-pocket fixed costs due to the costly capital investment and lack of volume to sustain a continuous production (Stavrulaki & Davis, 2010).

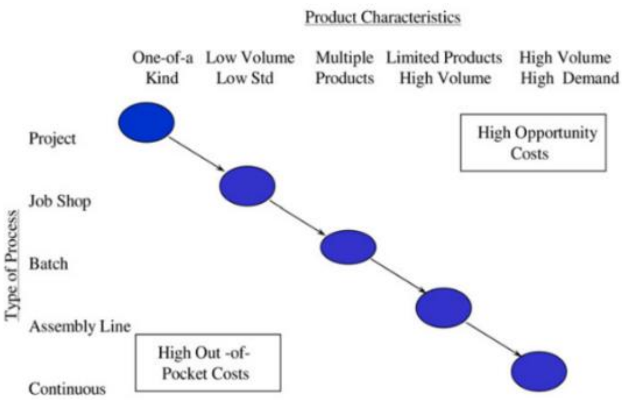


Figure 15. Hayes-Wheelwright’s product-process matrix (Stavrulaki & Davis, 2010)

5.2 Product and production system

A "production system" is a model that is assigned to a particular product and production process. In addition, models are selected based on their "decoupling point." This point defines the portion of the value system that responds directly to the customer, indicating the point in the value system where the client could provide their product requirements, norms standards or personal alternations to the end product (see figure 17) (Segerstedt & Olofsson, 2010). Because this applies to such a wide variety of industries, the same production system may be known by a variety of different names when referring to the repository of literary works. Nevertheless, the Assemble-To-Order (or Configure-To-Order) model suggests that the customer is able to have a certain amount of design freedom due to the selection of "unique features" to be able to personalize their product. This is because the customer is able to create their product according to their own specifications (Hoekstra & Romme, 1992). In the context of the transportation literature, the term "Ship-To-Stock" refers to Make-to-stock; a situation in which the client has very little to no possible input into the final outcome of the product.

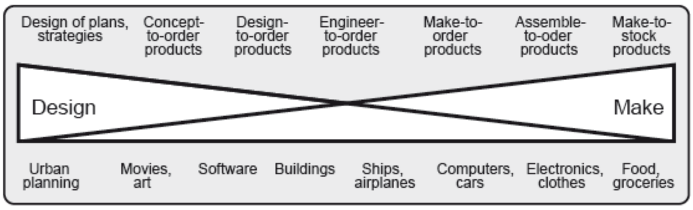


Figure 16. Production system types: design vs. make (Ballard, 2005)

Figure 16 displays a bandwidth designed by Ballard (2005), which allocated the various production systems. The bandwidth has two extremes, on the left are the distinctive one-of-a-kind projects, labelled under Design, and on the right are the manufacturing repetitious products, labelled under Make. Associated industries of the economy are positioned underneath the production system.

Modular buildings are composed of modules that are assembled in an off-site production facility and delivered to the construction site. These sets of modules are built with various standardized elements, such as floors, columns, walls, windows, etc. The complexity of the building, depending on the unique design features with limited standardization and repetition, will affect how the production system is set up in the off-site facility. More repetition in the design leads to less deviation in the production of the components, resulting in a more continuous assembly line. (Bertham, Fuchs, et al., 2019).

Currently, it is challenging to designate a single production system because of the variety of modular building methods and the wide variation in both volume and demand. The modular construction industry may benefit greatly from the industrialization that would result from the implementation of a suitable production system.

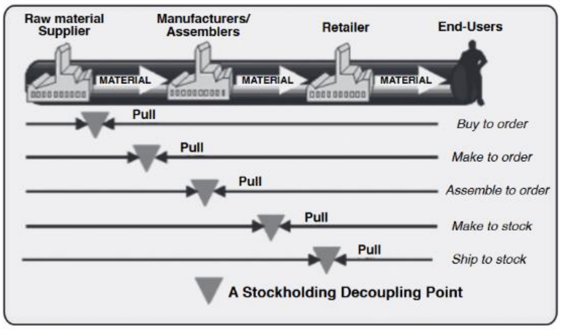


Figure 17. Decoupling point dictating the production system strategy (Hoekstra & Romme, 1992)

5.2.1 Concept-to-order

The design specification process is mainly based on client requirements, norms and standards. This model resides on the far end of the DESIGN spectrum, meaning the client has all the design freedom for the vision of the end product The client enters individually at the start of the information flow, before any interaction with a party or production disciplines. The "concept' in this matter defines the functionality of the product needs in relation to a particular market demand. Production will not begin until the client gives the go-ahead (Winch, 2003). This model may fit with individually unique products, where the client's requirements and vision of the product completely resonate with the end-product.

5.2.2 Engineer-to-order (Design-to-order)

While the word ETO is used in the literature, there is uncertainty about the right definitions and techniques, and as far as we know, there is a broad use of the model, and used interchangeably with design-to-order, due to the different industries it is used in (Gosling & Naim, 2009). The ETO supply chain 'decouples' at the design stage, so each client order influences the product design. Customization is key in the ETO supply chain. This indicates the consumer has ultimate authority. The ETO method enables clients to create things to match their own particular preferences at an early stage, allowing them greater choice in how they appear. With ETO, clients may express their preferences and wants in the final product design. (Duchi et al., 2014)

Product characteristics

ETO products are low-volume (typically one-of-a-kind), high in design variety, and costly, making most products different to the last. If possible, existing designs are fit to be modified to order, otherwise, new designs are developed. In the DTO supply chain, forecasting is seldom done since raw materials are either easily accessible or must be separately procured depending on the product's final design.(Stavrulaki & Davis, 2010)

Production characteristics

Lead times in the ETO supply chain are high since the designer and builder frequently engage with the customer directly. The great design variation offered to the customer necessitates a highly project-oriented ETO supply chain to provide production flexibility. Due to the vast variety of goods, it is normal for a new production process to be produced; nevertheless, when similarities arise, the production process will be adapted to the product in question. In ETO supply chains, the final-product is rarely stocked in an inventory.

Strategy

ETO supply chains must deliver high-quality products and services in an unpredictable environment. Agility is the best competitive strategy since it focuses on changing client requirements. "Agility" describes the supply chain's capacity to adapt to market developments. Agile supply chains include the use of flexible manufacturing methods, reduced lead times, information visibility, quick data availability, and collaborative connections (Stavrulaki & Davis, 2010; Swafford et al., 2006)

5.2.3 Make-to-order

MTO supply chains refer to a production system where goods are manufactured based on specific customer orders and designed to meet the individual specification of the customer. The main difference between MTO and other models is that the end customer has some input into the final product design, but it is still within the fixed design parameters set by the company. In MTO, the company allows a level of customization in product design and features, but not in the entire design.

Product characteristics

Make-to-Order (MTO) products have low volume, high design variety, and high cost, tailored to individual customers' needs with a high degree of design variety and customization. They are relatively expensive products that are built to meet the specific needs of individual customers. These products are typically low volume and high margin.

Production characteristics

Make-to-Order (MTO) is a production system where the company produces goods based on specific customer orders, rather than producing goods in advance and keeping them in inventory. The MTO production process typically involves the customer providing input on the final design of the product, but the design parameters are pre-established by the firm. The MTO process usually results in longer lead times as compared to Make-to-Stock (MTS) processes. The manufacturing process for MTO products is often highly flexible and can be tailored to the customer's specific requirements, allowing for the creation of unique and one-of-a-kind products. The emphasis is on providing customer-specific solutions, which requires coordination and collaboration with other suppliers and partners involved in the production process

Strategy

MTO manufacturers focus on establishing long-term relationships with suppliers of standardized components and materials, with a priority to ensure availability during sudden or seasonal surges in demand. A close relationship with suppliers can ensure reasonably priced, high-quality raw materials, but there can also be several barriers to attaining them in MTO supply chains such as flexibility and small order volume. To overcome these barriers, manufacturers must carefully map their supplier relationships to ensure the right balance of efficiency and flexibility with their supplier base.

5.2.4 Assemble-to-order (Configure-to-order)

Here the decoupling point is just before the manufacturing process. This gives the client some range to uniquely design the product to individual specifications, but with fixed design parameters which are pre-engineered beforehand. Clients have some say in the final product design by selecting from a number of predetermined standard components, but they have no say in the design of these components themselves. Despite set design specifications, these pricey, customizable products are made to satisfy the general demands of particular clients (Atan et al., 2017).

Product characteristics

As mentioned before, the product of ATO value systems uses a modular approach by using standardized components, efficiently produced in batches and then assembled to match the requirements. Research and development of these components have taken some time since they allow for considerable flexibility in design despite using a small palette of key components. Frequently, these items receive upgrades to include cutting-edge technologies.

Production characteristics

The ATO systems manufacturing line is configured with many continuous assembly lines in order to configure the final product. While there may be a defined standard, providing pre-engineered pieces for configuration will necessitate extra assembly lines in the facility. With this approach, integrated supply chain & long-term commitment are essential, as the assembly line has limited deviation. Therefore, due to the repetition, improvements can be made with the integrated team.

In contrast to the MTS supply chain, where the end product is instantaneously available to the client, the ATO supply chain involves some waiting. In sectors with significant product depreciation or high rivalry, it may be vital to reducing delivery times.

Strategy

The ATO supply chain must balance low cost, efficient production and delivery (both are required to be competitive) with a broad range of product diversity. Therefore, the ATO system must implement the agile and lean elements in its capabilities. The term "leagile" describes this separation of lean and agile approaches. Separation at this point indicates the transition from lean to agile methodology. This separation occurs at the point of final production or assembly in most value chains. To maximize efficiency in both manufacturing and distribution, ATO manufacturers, like BTS manufacturers, often form lasting relationships with their many suppliers (Atan et al., 2017; Stavrulaki & Davis, 2010).

5.2.5 Make-to-stock

This strategy resides on the MAKE side, meaning a total manufacturing process with very limited to no input from the client into the design of the product. While the end consumers may have a choice in products, none of the products associated with this supply chain is made specifically for individuals. They are produced for the broader public. In traditional manufacturing, the decoupling point is at the retailer or the distributor.

Product characteristics

As a result of their effectiveness for mass-produced products with little margin for error, MTS production systems are widely used. They represent the pinnacle of standardization with a low degree or no variation in design. These low-priced items have a constant demand, therefore reliable demand forecasts are possible with a small margin of error if sufficient previous demand data is provided.

Production characteristics

The manufacturing process for these advanced, highly standardized items has a primary emphasis on attaining low-cost operations, which are often achieved via high-volume transformation processes. The finished products are created on an assembly line that runs continuously and is stored in inventory in advance of the demand. Also, the production process is often highly automated, which results in either very little or no human labour.

Strategy

The MTS strategy focuses the most on cost reduction, which is achieved with the lean strategy. Studies have concluded that the lean approach works best when demand is relatively stable and product variety is low, as characterized by BTS supply chains. (Christopher, 2000). Due to the manufacturer's high volume and the supplier's long-term commitment, collaborative partnerships with suppliers are also a common characteristic. Therefore, most of the manufacturing industries are integrated throughout the value system (Lau et al., 2010). Consequently, information-sharing activities such as rapid response, efficient customer response, and vendor-managed inventory are common in BTS supply chains due to their cost-reducing effect. (Stavrulaki & Davis, 2010)

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6

Value Chain Integration

6. Value Chain Integration

The success of any construction project relies on the smooth and efficient functioning of the value chain. Value chain integration (VCI) is an essential approach that ensures all aspects of the value chain work together seamlessly to achieve the desired outcome. The effective management of the value chain can improve the coordination of resources, reduce waste and errors, and increase the overall efficiency of the construction process. In this chapter, we explore the role of VCI in the construction industry and examine the shift from traditional supply chain management to value chain management. We will also discuss the factors for VCI, which are essential for achieving successful integration of the value chain. Finally, we will provide a preliminary CSF list.

6.1 The role of VCI

Merging different disciplines is considered complex to facilitate due to conflicting interests, objectives and ambitions. To address these issues, there is a need for more integrated ways of working and collaboration. Supply chain integration has been traditionally implemented in manufacturing by focal companies to align and synchronize the processes of suppliers with their business processes (Choi & Krause, 2006). However, this approach has not been fully adapted to the building industry, despite its potential to improve performance and address issues such as low effectiveness and efficiency, lack of innovation and difficulties in knowledge sharing and learning (Vrijhoef, 2011).

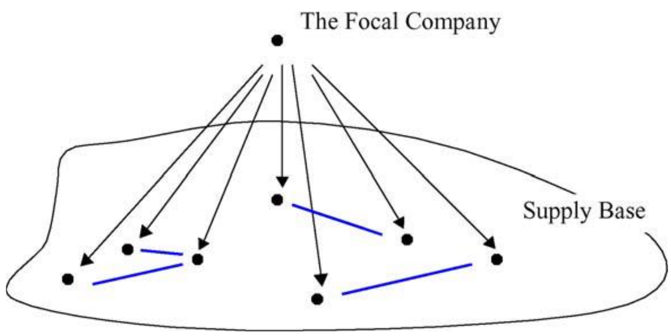

Figure 18. Focal company and its supply base. (Choi & Krause, 2006)

In the modular construction industry, integrating project and product disciplines into the value chain has been a longstanding challenge for researchers and practitioners. According to Gamma et al. (2020) poor integration can lead to silo-thinking, were departments are focusing on their own goals and operations, rather than on the organization as a whole. Silo-thinking often leads to a lack of communication and collaboration between different parts of the organization, which can hinder efficiency. One way to streamline the construction process is through industrialization, particularly prefabrication. Prefabrication cause transferring activities from the construction site to earlier stages of the supply chain, due to working with predefined elements, for example, putting more emphasis on defining the design specifications prior to the project. However, this can also increase the complexity of the value system and make the process more vulnerable to silo-thinking

This is where the theory of Role 3 comes in, which suggests that transferring activities away from the construction site requires proper management of the value system to fully realize the benefits of industrialization. (Vrijhoef & Koskela, 2000).. To overcome the objective limitations of transferring activities off-site, it is important to manage the value system effectively. This is particularly relevant for make-to-order and assembly-to-order production systems, which can also be subject to problems and waste if managed in a traditional manner. Therefore, in the modular construction industry, it is crucial to integrate project and product disciplines into the value chain while also taking into account the challenges of industrialization and the need for effective value chain management to fully realize the benefits of prefabrication and other forms of industrialization. (Vrijhoef & Koskela, 2000).

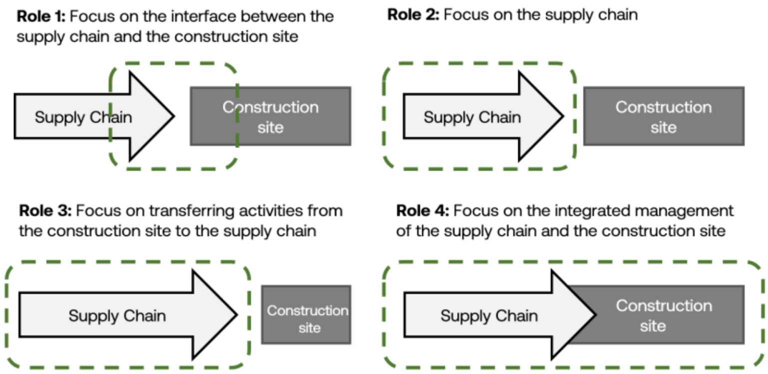

Figure 19. The four roles of SCM in construction (Vrijhoef & Koskela, 2000)

6.2 From SCM to VCM

In the field of business management, Supply Chain Management (SCM) and Value Chain Management (VCM) are important concepts that are related but have distinct differences. SCM can be defined as the management of material flows across functional boundaries within an organization, to improve efficiency and reduce costs. The origins of SCM can be traced back to the early 1980s when industries began to broaden the concept beyond the borders of one firm to include all organizations and business units involved in supplying a product or service to the end consumer. Jones (2012) argues that *"SCM provides the means by which the integration of project processes and partners can be extended beyond the boundaries of construction projects to their supply chains"*.

VCM, on the other hand, is a systematic approach to enhance and sustain the competitive advantages of all participating firms (from suppliers to end-users) through four strategies: satisfying the needs of all participating firms and end-users, evaluating the strengths and weaknesses of all firms within the production line, identifying all activities where they can generate value, and improving linkages and communication among all firms (Wong et al., 2004). The concept of a cross-functional team is an important aspect of VCM, where a group of people with different skills work together in a highly interdependent manner to achieve a common organizational objective. The main differences are displayed in table 5 below.

Tabel 5 SCM vs. VCM

Characteristics	Supply Chain Management (SCM)	Value Chain Management (VCM)
Integration	Integrate all activities and processes across the supply chain	Coordinating activities of cross-functional departments to work together effectively
Purpose	Requires visibility into the entire supply chain to identify bottlenecks, delays, and inefficiencies	Understanding the various activities that are necessary to create a product, and determining which ones are critical to success
Collaboration	All stakeholders involved in the supply chain work together in a collaborative manner	Building strong relationships with suppliers and other external partners to ensure that the value chain is integrated and effective
Cost-effectiveness	Finding the most cost-effective ways to source materials, produce goods, and deliver them to customers while maintaining the required quality and service levels	Continuously looking for ways to improve the efficiency of the value chain and reduce costs
Strategy	Adaptable to changing market conditions, technologies, and customer needs	Being able to quickly adapt to changes in the market or in customer demands

In other words, SCM focuses mainly on the supply and logistics of products, while VCM focuses on a more comprehensive and wider aspects of the business operations that include the supply side, but also the development and marketing side to ensure meeting customer demands and creating value for them. When it comes to modular construction, both SCM and VCM are important considerations. According to Gosling et al. (2016) modularity can be viewed from both a design-based and an operations-based perspective, and it is important to consider modularity in an integrated way across all phases of the project life cycle. Additionally, effective collaboration between designers and site operators is necessary for the successful implementation of modular approaches. As stated in the prior chapters, the modular process could benefit by transitioning to a product-based approach and adopting the manufacturing methods such as supply chain management (SCM). Since the 1980s, there has been an increase in the number of SCM efforts launched, but none have been effective because of the industry's partiality and fragmentation (Vrijhoef & Koskela, 2000). However, in the last 20 years, there has been an increase in traction in the offsite construction community for SCM. Since traditional SCM is largely to blame for waste and other issues, improved adaptations of SCM concepts and techniques should provide a solution.

In the context of modular construction, value chain management is important to ensure that the different stakeholders involved in a modular construction project work together seamlessly throughout the design, manufacturing, transportation, installation and delivery process. This includes ensuring that the design of the modular components are optimized for manufacturing and transportation, coordinating logistics to minimize delays and waste, and managing the installation process to ensure that the modules are assembled correctly.

6.3 CSFs for Value Chain Integration

Several CSFs are necessary to enable successful value chain integration in the modular construction industry. A comprehensive literature review was conducted to identify CSFs that contribute to successful integration in modular construction and related industries. The review was conducted following the steps in chapter 3.2.2.

1. Exploration of key areas that are critical to the success of **value chain integration.**

The initial gathering of the different CSF is through searching different keywords "modular construction", "critical success factors", "value chain integration", "cross-functional integration", "opportunities, benefits and challenges", and similar terms and definitions. The review included studies published between 2000 and 2022 and focused on literature related to the integration of value chains, supply chains, and value systems, as well as on industries that utilize product approaches and pursue long-term commitments and partnerships. The review identified 15 studies containing a total of approximately 300 CSFs. The list of literature used to gather this list is to be found in Appendix C. Most of the CSFs were already labelled and put into categories. Based on these categories, the list was filtered down with a focus on CSF regarding the development part of the project. Furthermore, there were categories which were out of scope such as finance, logistics and risks aspects. At the end of the filtration the list was narrowed down to 130 CSFs, see Appendix D.

2. Create **categories**: filter and consolidate list.

These factors were analysed and filtered to identify those that were relevant to successful integration within a modular environment between internal parties. The process of categorizing the remaining CSFs involved repeatedly reviewing the factors and adjusting the titles of the categories to ensure that they were logical and coherent. Similar factors or duplicates were carefully examined and either outweighed each other or combined into a single factor. This helped to clearly and effectively organize the CSFs. This resulted in defining eight categories: “Collaboration”, “Communication”, “Information sharing”, “Culture, “Adequate experience”, “Modular production principles”, “Coordination” and “System structure”. Underneath each category, one can find the factors essential to enabling value chain integration. A correlation could also be found between the categories, which resulted in adding those into the labels “Synergy”, “Competence” and “Value system management”. The result is displayed in table 6.

Review the papers in each category and filter out any that are not relevant or do not provide valuable information. Consolidate any duplicated information or similar concepts under one main point. Addressing the labels; synergy refers to the way that different team members or departments work together effectively to achieve common goals. This can involve the coordination of efforts, the sharing of information or knowledge, and the alignment of values and objectives. Competence refers to the knowledge, skills, and abilities that are necessary to perform tasks effectively. In the modular construction industry, it is important for all stakeholders to have the competence required to contribute to the value chain. Value chain management involves the planning, coordination, and control of activities within the value chain to create value for the clients and achieve a competitive advantage. By effectively managing the value chain, companies in the modular construction industry can improve efficiency, reduce costs, and increase customer satisfaction.

3. Create the **preliminary list.**

Review the final list of CSFs and make sure that the information is clear and easy to understand. Organize the information logically and coherently, and remove any unnecessary details. It is important that the list is complete and covers all relevant aspects of the modular construction industry. By following these steps, a clear and comprehensive overview of the CSFs to enable successful value chain integration in the modular construction industry is created. In the next phase of developing the final list of critical success factors (CSFs), the initial list presented in table 6 will serve as a coding tool to organize and structure the unstructured qualitative data, as elaborated in section 3.3.3.

The Labels dissect into Categories, which then disintegrate in the various CSFs. This breakdown displays initially the different classification areas of improvement and within those areas the accompanying categories. The Labels are set classifications of the CSFs, which provide some continuity and guidance for the entirety of the research. However, due to the current lack of validity of the CSFs being enabled to integration teams, the Categories are still mouldable.

Note: The CSFs are numbered, this, however, does not imply an indicative hierarchy of importance.

Table 6. preliminary CSF-list for integration.

Label	Category	Critical Success Factor
Synergy	*Communication*	1. Effective communication
	Collaboration	2. Collaborative working environment
		3. Long term partnership
		4. Established collaboration structure
		5. Early involvement of key parties
	Information sharing	6. Early and effective use of information/communication technologies
		7. Frequent information/knowledge sharing
	Culture	8. Thrust among employees
		9. Morale and motivation
		10. Top management commitment
Competency	*Adequate experience*	11. Adequate technical and practical experience and knowledge
		12. Maturity of techniques through retrospective feedback
	Modular production principles	13. Early design freeze
		14. Defined design & technical specifications of product
Organization	Value Chain Management	15. Coordination between interfaces
		16. Early planning and scheduling
		17. Organizational structure

The upcoming paragraphs will provide a literary elaboration of the seventeen CSFs, organized into three main labels: "Synergy," "Competency," and "Organization." Each section will explore a subset of the CSFs in detail, offering a comprehensive overview of the factors that contribute to success in modular construction.

6.3.1 Synergy

Synergy refers to the concept that the combined effect of two or more things is greater than the sum of their individual effects. In other words, synergy occurs when the whole is greater than the sum of its parts. Synergy can occur in many different contexts, including business, technology, and organizational development. In a business context, synergy can refer to the increased efficiency and effectiveness that can result from combining different functions or processes within an organization. For example, a company may achieve synergy by integrating departments, or by combining efforts with those of another company. In organizational development, synergy can refer to the way that different team members or departments work together effectively to achieve common goals. The four most recurring factors to achieve synergy within an organization are a combination of collaboration, communication, information sharing, and culture.

Communication

Communication is also crucial for creating synergy, as it helps to ensure that all stakeholders are aware of what is happening within the organization and can work together effectively.

CSF 1 – Effective communication

Effective communication is crucial for facilitating the exchange of ideas and visions, which can lead to mutual trust and understanding among partners. This requires the establishment of effective communication channels, which can be used to motivate partners to collaborate in goal setting and planning (Cheng et al., 2000). According to Kamar et al. (2010) effective communication channels in the supply chain are essential for coordinating processes and addressing critical scheduling from the beginning to the end of a project. In the design phase, effective communication and integration among the team, including designers, construction team, and manufacturers, is necessary to avoid the need for redesign and additional costs and time. Good communication can also contribute to synergy within the team, as it allows partners to share knowledge and resources more effectively, leading to improved efficiency and outcomes (Ismail et al., 2012; Li et al., 2018; Wuni & Shen, 2020).

Collaboration

Collaboration in the context of modular construction projects refers to the effective cooperation and coordination between different team members and departments, in order to achieve shared goals and objectives. This is seen as a critical success factor in ensuring the successful outcome of modular construction projects. Studies have identified the importance of managing collaboration as a key area to achieving success in such projects (Wuni & Shen, 2019).

CSF 2 – Collaborative work environment.

The probability of collaboration decreases significantly with the distance between two teams, falling below 10% when the offices are separated by 10 meters or more. This is because separation reduces the chance of meetings and information sharing, and **increases** isolation which cultivates cultural differences, such as jargon and perceived personality differences (Allen, 1977). Co-location increases the chances of meetings and information sharing, as well as improving face-to-face communication and decision-making. Co-locating refers to the practice of bringing together or locating different teams or departments in the same physical location to facilitate more frequent and efficient communication and collaboration, which can lead to improved productivity (Holland et al., 2000).

Breaking down barriers between departments, such as research, design and manufacturing is important in order to learn about and address problems encountered in production and assembly. Visiting the factory to see and hear about these problems can be beneficial (Deming, 1981). Partnering workshops, which are facilitated in a friendly and open environment, are often used in construction to stimulate participation and achieve, e.g., joint targets for procuring a project in a way that does not jeopardize cost, time, quality, or safety (Cheng et al., 2000).

CSF 3 – Long-term partnerships
Developing long-term collaborative inter-organizational relationships can develop trust through greater mutual understanding, increased mutual competitive advantage, greater transparency in transactions and more commitment, leading to improvements in the team's performance from project to project over a period of time and better communication across the interface structures (Jones, 2012).

Long-term partnerships often involve the integration of internal teams in order to facilitate collaboration and cooperation. This can involve co-locating teams in the same physical location, or implementing systems and processes that allow for seamless communication and coordination. By integrating teams within a long-term partnership, organizations are able to achieve greater synergies and more effectively share knowledge and resources. This can lead to improved efficiency, productivity, and outcomes, as well as a deeper understanding of markets and the external environment (Cheng et al., 2000; Holland et al., 2000; Wuni & Shen, 2019).

CSF 4 – Established collaboration structure
An established collaboration structure within an integrated value chain is important for facilitating communication and coordination, building trust and cooperation, and adapting to changes. Having a systematic collaboration structure in place enables teams to approach project planning more efficiently, as it will be a defined routine. It leads to improved efficiency, decision-making, and problem-solving within the value chain. By establishing clear lines of communication and collaboration, organizations are able to work together to identify and address any challenges or opportunities that may arise frequently. Overall, an established collaboration structure is an essential component of an effective and efficient integrated value chain (Holland et al., 2000; Wuni & Shen, 2019; Yuen et al., 2019).

CSF 5 - Early involvement of key parties
In order to be successful in the modular construction industry, it is crucial to involve key players such as engineering designers, owners, and fabricators in the earliest stages of a project. Without this collaboration, fabricators may be at risk of manufacturing modules based on incomplete design specifications, which can lead to problems later on (Wuni & Shen, 2019, 2020). It is also important to involve these key players throughout all phases of the project, as their expertise and experience can be invaluable in anticipating and avoiding potential issues in the value (J. O. Choi et al., 2020). In addition, involving these stakeholders at the design stage allows them to understand and appreciate the decisions that may impact their roles and responsibilities on the project. Early collaboration with all stakeholders is essential for successful standardization and can help to create a supportive and collaborative environment for the project's implementation (Wuni & Shen, 2021).

Information Sharing

Effective communication and sharing of information are crucial for value chain integration in a modular construction project. It allows all team members to be on the same page and have access to the necessary information to perform their roles efficiently

CSF 6 – Early and effective use of information/communication technologies
By leveraging digital technologies such as building information modelling (BIM), enterprise resource planning (ERP) systems, and internet of things (IoT) solutions, organizations can improve the accessibility, accuracy, timeliness, and formatting of the information being shared across the **supply** chain (Yuen et al., 2019). This can help cross-functional teams to improve communication, coordination, and efficiency by coordinating the various activities of the process. For example, the use of digital technologies can help to automate and streamline processes, such as the exchange of design drawings and the tracking of materials and components. This can help to reduce the risk of delays and disruptions and ensure that projects are completed on time and within budget (L. Li et al., 2018; Wuni & Shen, 2020, 2021).

CSF 7 – Frequent information/knowledge sharing
The importance of sharing accurate and vital information and documents in order to achieve successful project outcomes has been demonstrated in various studies (Holland et al., 2000). Effective communication and information sharing are crucial for ensuring successful synergy among independent stakeholders and avoiding disruptions in the **supply** chain, leading to successful project delivery that meets the requirements of the client and profitability for the integrated teams. Previous research has demonstrated

that communication and information sharing can help to reduce misunderstandings, manage risks, and improve the efficiency of workflows within the supply chain. (Vrijhoef & Koskela, 2000; Wuni & Shen, 2020)

Culture

A cohesive and supportive work environment that encourages cooperation and mutual support can lead to the establishment of a synergy and efficient team dynamic within the organization.

CSF 8 – Trust among employees

A company culture that promotes teamwork and collaboration is essential for the development of trust among team members. Trust is essential for "open" relationships, as it can reduce stress, increase information exchange and problem-solving, and lead to better outcomes. Trust is also reinforced by teamwork and can increase inter-functional collaboration (Cheng et al., 2000; Holland et al., 2000). Trusting team members are more likely to share information, admit uncertainty, seek help, and suggest creative ideas. A willingness to change and be open to learning is also linked to effective cross-functional collaboration. Team members who adopt new attitudes, mindsets, and behaviours as part of their teamwork can help create a climate of inclusion, where people from different functions are viewed as insiders as they know what their colleagues are capable of.(Holland et al., 2000)

CSF 9 – Morale and motivation

High levels of employee morale and motivation can contribute to the successful integration of cross-functional teams by fostering a positive work environment and encouraging collaboration. When team members are invested in the success of the project and feel valued by their colleagues and management, they are more likely to be motivated to work together effectively. Clear, achievable goals can also help to boost morale and motivation by providing a sense of purpose and direction for the team.(Azhar et al., 2013; Cheng et al., 2000). Cohesiveness, or the bond between team members and the organization, is another important factor that can contribute to successful integration. When team members feel connected and aligned with the company's vision, they are more likely to be passionate and committed to achieving success. (Holland et al., 2000; Yuen et al., 2019)

CSF 10 – Top management commitment

The commitment of team managers to their employees is an important factor in the successful integration of cross-functional teams. This involves actively modelling and promoting desired behaviours and values, actively supporting and participating in learning and change efforts, and being willing to share power and authority while still holding people accountable (Cheng et al., 2000; Wuni & Shen, 2019) Top-down commitment is important at all stages of the process. The support and commitment of senior management is critical, as they formulate the strategy and direction of business activities. It is also important that the goals and objectives of each organization involved in the project are compatible and aligned. A clear mission from senior management, or a clear vision of the purpose of cross-functional teams within the organization, is also necessary for successful cross-functional team working.(Azhar et al., 2013; Ismail et al., 2012; Yuen et al., 2019)

6.3.2 Competence

By examining the competencies of individuals involved in the modular construction process, such as developers, architects, and manufacturers, this research aims to provide insights into the critical success factors that contribute to the success of integrated value chains in modular construction. The goal is to identify the key competencies required for individuals to effectively collaborate and achieve successful outcomes in the modular construction process.

Adequate experience

CSF 11 – Adequate technical and practical experience and knowledge

It is essential that key players in modular construction projects possess a high level of technical and practical experience and familiarity with modularization in order to ensure the successful implementation and high quality of these projects (Azhar et al., 2013; O'Connor et al., 2014). These players must possess expertise in areas such as design, manufacturing operations, assembly, digital technologies, contracting, supply chain management, project integration, production engineering, and process efficiency (Wuni et al., 2020; Wuni & Shen, 2020). Without sufficient knowledge and experience in modular design, manufacturing, and project management, the risk of costly design errors, production delays, and project failures increases significantly (Bertram et al., 2019). For example, inexperienced designers may create designs that are not feasible for manufacturing or assembly, leading to costly redesigns and production delays. Similarly, fabricators with limited technical capabilities may produce components that do not meet the specified quality standards, leading to costly defects and reworks. Furthermore, project management teams with insufficient knowledge of modular construction may struggle to effectively coordinate and integrate the various stages of the project, leading to delays and cost overruns (L. Li et al., 2018; Wuni, Shen, & Osei-Kyei, 2022). Having sufficient knowledge throughout the company leads to better integration as all players involved understand the implications and benefits of working in a certain way. This, in turn, helps to create value and a competitive advantage for the company and its partners. Therefore, it is essential that key players in modular construction projects have adequate technical capabilities and practical experience to ensure the success of the project.

Standardization of modules and product configuration in modular construction can improve integration in the value chain by increasing scalability. When modules and products are standardized, it allows for mass production and specialization of labour, which can increase efficiency and reduce costs. In addition, standardization allows for the customization of modular systems, which can meet the specific needs of different projects while still maintaining efficiency. Overall, standardization and benchmarking of best practices can help to improve the success and competitiveness of modular construction projects by enabling greater integration in the value chain.

CSF 12 – Maturity of techniques through retrospective feedback

The maturity of techniques used in modular construction projects, such as building information modelling (BIM) technology, is important because it can expedite the learning curve and improve the organization's understanding and efficiency in the processes involved (Nawi et al., 2012). This can lead to better cross-functional collaboration and a willingness to change among team members (Holland et al., 2000), which is essential for the success of modular construction projects. The detailed design phase, in particular, requires a high level of technical knowledge and skills to transform construction drawings into assembly drawings with accurate dimensions and connection methods (L. Li et al., 2018)

Systematic performance measuring and re-use of experiences refer to the practice of collecting and analyzing data on the performance of a modular construction project in order to identify areas for improvement and to inform future projects. This includes gathering retrospective feedback from team members and stakeholders, and analyzing data on cost, schedule, and quality to increase the maturity of techniques used in modular construction projects, leading to better coordination and collaboration between stakeholders and ultimately, more successful projects (Kamar et al., 2010; Wuni, Shen, & Osei-Kyei, 2022; Wuni & Shen, 2019).

Production principles

CSF 13 – Early design freeze

In modular design, the design of the components or systems needs to be frozen early on in the project in order to begin manufacturing the relevant modules as soon as possible. This is because any modifications to the design after manufacturing begins may affect how the different components and modules fit together, leading to delays and increased costs (O'Connor et al., 2014; Tsz Wai et al., 2021; Wuni & Shen, 2019). This is different from traditional construction where clients typically exercise their authority to change the design, and freezing the design early requires them to adopt a completed design even before module manufacture begins.

With modular production, the form of the building becomes the assembly of pre-designed modules. Therefore, it may be possible to postpone certain design decisions until later in the project without affecting the overall construction process. However, it is still important to have an early design freeze for the relevant components and systems to minimize the risk of costly design changes and ensure the success of the project. (Choi et al., 2020).

In terms of the understanding of the "project," the emphasis in modular construction is on the design and manufacturing processes rather than the on-site construction process. The success of the project depends heavily on the effectiveness of these processes, including the early design freeze by considering the design principles such as reduced interdependency between elements, controlled design variants, and minimal allowance for changes in design sequences. (J. O. Choi, 2014)(Wuni & Shen, 2020).

CSF 14 – Defined design & technical specifications of product

One important factor in the successful implementation of modular construction projects is the accuracy of the design phase. If errors are made at this stage, it can result in the production of components that are not consistent with the overall scope of the project, which can be costly to correct. It is important for designers, clients, engineers, fabricators, and contractors to collaborate and share information during the design phase, as decisions made at this stage can have an impact on the roles and responsibilities of these stakeholders throughout the project life cycle.

Wuni and Shen (2020) identified 9 critical success factors (CSFs) for the management of modular construction projects. CSF2 *"robust design specifications, accurate drawings, and an early design freeze"* was ranked as the most important. This CSF has significant positive correlations with five other CSFs, including *"Effective stakeholder management", "Early engagement of key players such as designers, engineers, fabricators, and contractor"* and *"Adequate experience and technical knowledge of key participants"* indicating that its effective implementation can greatly contribute to project success and the collaboration potential between the players of an integrated value chain.

6.3.3 Value chain management

VCM, or value chain management, is a method used by companies to optimize their operations by evaluating the needs of end-users and the strengths of partners, and by coordinating and integrating all activities that contribute to creating value throughout the production process. This approach helps companies to gain a competitive edge, reduce costs, increase profits and grow market share (Porter (1985). As Wong et al.(2004) stated "VCM aims at optimizing project values by better management of the transition points along the project period". The following factors have been identified to enable this statement:

CSF 15 – Coordination

Effective management of modular construction projects necessitates the coordination and integration of various players within the value chain, by one or multiple parties, to ensure the successful management of cross-functional departments and the supply chain (Wong et al., 2004). Kamar et al. (2010) and Tsz Wai et al. (2021) emphasized the importance of value chain integration for the success of modular construction projects, as the supply chain for modular construction projects is complex and can be disrupted by a variety of factors. Wuni and Shen (2020, 2021) also highlighted the need to effectively manage the supply chain and stakeholders in modular construction projects. In order to achieve this coordination and integration, building information modelling (BIM) and other digital construction technologies can be utilized to improve communication and collaboration among value chain partners. When coordination is lacking, it can lead to negative consequences such as a breakdown in trust and a lack of commitment among parties, which can lead to conflicting relationships. To improve coordination, it is crucial to increase communication and share information about the expectations of each party involved. Additionally, coordination, among others, is crucial in order to achieve mutually fulfilled expectations and stability in the uncertain environment of modular construction projects (Cheng et al., 2000).

CSF 16 – Early planning and scheduling
Early planning and scheduling are important factors for coordination in modular construction projects. This is because modular manufacturing scheduling is a crucial aspect of the modular construction process and inefficient scheduling has been identified as a critical risk factor in several studies (Li et al., 2017; Wuni et al., 2020; Wuni, Shen, & Mahmud, 2022). Modular construction is different from traditional construction in that the manufacturing process lies between made-to-order to make-to-stock and follows an engineer-to-order enterprise resource planning model. This means that the quantity of each modular component produced must match the exact demand for that component in the project and inventory must be returned to zero at the end of the project(Wuni, Shen, & Mahmud, 2022). As modules are designed to meet the specific requirements of a single project, shortages cannot be covered by other manufacturers unless they are designed using the same specifications. This underscores the uncertainties and risks associated with inefficient scheduling. Effective planning and scheduling can improve coordination and ensure the successful implementation of modular construction projects by providing a clear understanding of tasks, optimizing tactical and operational plans, and considering the true constraints of the market, manufacturing plants, and logistics (Ismail et al., 2012).

CSF 17 – Organizational structure
In the integration of the production supply chain, "Design for supply chain management" was identified as the most important factor in modular construction projects (Wuni, Shen, & Mahmud, 2022). This design approach involves incorporating specific guidelines and rules into the project design to ensure that it is optimized for effective supply chain management that aims to improve coordination and management. Thus, the design for SCM adopts an integrated approach to enhance effective SCM. This includes involving relevant project partners in the design process to establish a common goal of improving overall performance and implementing systems for collaboration, information sharing, decision synchronization, alignment on responsibilities, and innovative supply chain processes. Essentially, it is a strategy to ensure that the supply chain aspects of a project are well thought out and planned before the project is executed, to ensure a smoother and more efficient process.

Within this research, the goal is to gather knowledge about the factors that will enable the successful integration of the value chain of a modular construction project. In the production supply chain integration is has been substantiated that the largest factor is to establish an embedded organization structure that enables the adoption of supply chain integration. Whilst the value chain includes most of the supply chain activities, it is interesting to test this factor for relevance to the integration of the value chain. This method involves engaging relevant project partners early on, such as suppliers and manufacturers, to establish a common goal of improving overall performance.

PHASE 2

CASE STUDY

Source: Lister

7

The Case: Lister Buildings

7. The Case: Lister Buildings

This chapter provides an in-depth analysis of Lister Buildings, a modular and circular construction company. It begins with an overview of the company, including its history, vision and mission. It will then delve into the company's organizational structure, value chain and production system, examining the different components and how they interact with one another. The information gathered will serve as the foundation for the case study, which will be used to identify key areas for improvement in the integration of the value chain in modular construction projects.

"How can we build more sustainably, faster, and affordably? With the goal of solving the housing shortage while making a positive contribution to people and the environment."

7.1 Vision

Lister Buildings is a real estate life cycle platform that specializes in the development, design, engineering and manufacturing of modular wooden residential buildings, which they eventually manage. Their focus is on long-term sustainability, with an emphasis on addressing climate change, resource scarcity, and the importance of human health in the built environment. They incorporate technology such as digital twin creation, BIM systems, and internal communication tools into every aspect of their operations, from planning and development to design, building, and manufacturing, to ensure effective digital management and transparency between departments.

One of the key elements of Lister Buildings' vision is its commitment to chain integration, improving its processes over time to achieve the best possible outcome. They have a production facility in Weert, where they manufacture the modules for their buildings, which is a critical aspect of their value chain. By collaborating with external partners such as architects, structural engineers, and timber suppliers, Lister Buildings is able to create a comprehensive construction platform that increases productivity, reduces failure costs, and improves overall results.

In addition to managing their own projects, Lister Buildings also works with institutional investors and housing associations to make their finished projects available for the rental market. They typically work on projects through a design and build assignment, taking on either a lead developer or general contractor role. Through their digital platform and commitment to collaboration and sustainability, Lister Buildings is positioning themselves as a leader in the modular and circular construction industry.

7.2 Organization & The value chain

Within the Lister Buildings entity, there are four different departments: Lister Development, Lister Architecture, Lister Systeemontwikkeling and Lister Manufacturing. Together they form the internal integrated value chain, bringing a number of benefits such as improved productivity, coordination, flexibility and quality performance by combing efforts to optimize and streamline processes (Gamme et al., 2020). The company is divided into several departments, each with their own specific roles and functions within the integrated value chain.

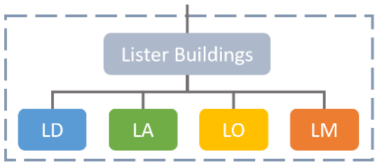

Figure 20. Organisation structure Coebax B.V.

Lister Development [LD] is responsible for the planning and development of new projects. They are considered the principal in ongoing projects, being the party to manage the project from acquisition up to delivery. This includes, but is not limited to, identifying potential sites, acquisitions, conducting feasibility studies, stakeholder management and obtaining the necessary permits and approvals. They work closely with architects, engineers, and other professionals to design and plan the building projects. In a modular construction environment, development main adjustment has to deal with decreased design freedom which could be experienced as limiting, however, due to the beneficial aspects of modular construction clients have regained interest in alternative building methods.

Lister Architecture [LA] is responsible for the design of the buildings. This includes creating detailed architectural plans, selecting materials, and ensuring that the design meets all relevant building codes and regulations. They also work closely with Lister Development to ensure that the design is feasible and can be built within budget. The idea is to design with standardized modules within the building plot, leaving the unique feature to be the main features of attention. Up to recently, after the first version of the standardized module was released, LA, together with cepezed, used to be involved with system development of the modules to be used for multiple projects, but is currently focussed on the ongoing projects, while LO covers those responsibilities. LA is also working on standardization of the design process, as this can be used for future design processes within Architecture.

Lister System-engineering [LO] is the research and development team and is responsible for the engineering and system development of the modules. This includes creating detailed structural plans, improving and innovating the module through research and development, selecting materials for the structures and nodes, and ensuring that the module is safe and stable. LO currently works on the development of a standard benchmarking building, in order to arrive at the minimum price level of the Lister system, which creates a foundation to create standard Lister house plans. They are less involved in specific projects but play a key role in the overall development process. They work at a higher level, providing guidance and advice to other departments to ensure that the designs are feasible and can be constructed (within budget).

Lister Manufacturing [LM] takes most responsibility during the realisation phase for the production of the modules. This includes the process of bringing together various components to form the modular units that make up the final structure. Once the development phase is completed, the design is passed on to LM who takes the design and creates detailed production plans and clear instructions for the assembly team to follow. Also, the suppliers, such as Stora Enso, CLT-S and TNM, are in direct contact with LM to deliver their components to the factory. LM also work closely with LO to ensure that the modules are manufactured to the correct specifications, and with LA and LD to ensure that the final building meets all relevant building codes and regulations.

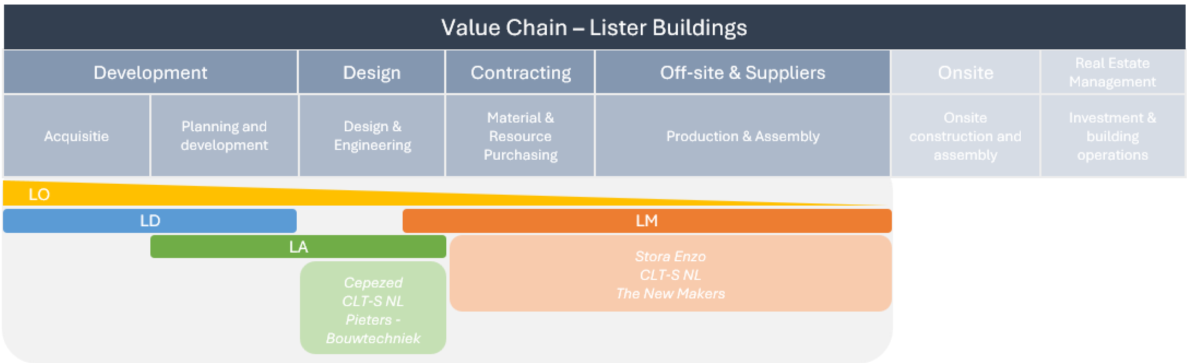

Figure 21. Value Chain Lister Buildings (o.i., 2022)

Lister Buildings has close relationships with a number of external partners to create a construction system for their modular wooden residential buildings. **CLTS** is a constructor of wooden construction and plays a crucial role in the building process. They are responsible for creating the wooden elements that make up the modules of the final building. **Cepezed**, an experienced architectural bureau in circular design and demountable design, was responsible for the initial system design. Their expertise in structural, demountable and system thinking is a key parameter of circularity. Due to the completion of this specific task, cepezed will be gradually transitioning out of their positions. **Pieter Bouwtechniek** is the permanent structural engineer which is responsible for ensuring that the design and construction of the building meet all necessary structural requirements, such as stability and safety. **Stora Enso**, a leading timber supplier and one of the largest forest owners in the EU, provides Lister Buildings with the highest quality sustainably managed wood. This is important to Lister Buildings because it helps them score well in the MPG (Milieu Prestatie Gebouwen) which is the environmental performance of buildings in the Netherlands. Lastly, **The New Makers** (TNM) specializes in kitchens, bathrooms, and toilets, bringing a high level of functionality and design to these essential areas of the building. They provide a wide variety of styles and options to meet the needs of different projects, which arrive in flatpacks and are installed as units into the modules.

7.3 Project delivery process

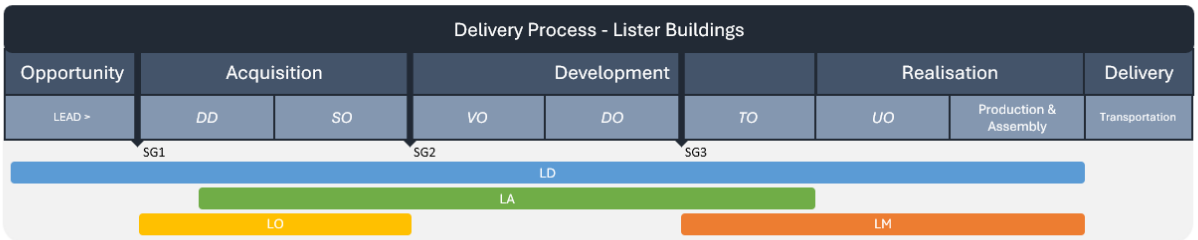

Figure 22. The delivery process of Lister Buildings (o.i., 2022)

The delivery process of Lister Buildings has been re-evaluated during several workshops of an industry expert with decades of experience in the construction industry. Notably, the delivery process diagram in figure 22 closely follows the traditional construction format. This could be the outcome of developing a new delivery procedure with professionals who may lack the knowledge and experience in the modular construction industry to advise Lister Buildings personnel who are having difficulty finding a delivery structure that fits their mix of disciplines.

The process starts with the **Opportunity** phase, where LD initiates a project by identifying potential sites, acquisitions or joining in on tenders. LD conducts market research, site analysis, and other activities to determine the feasibility of a project. Once a potential opportunity has been identified, the next step is to acquire the land or property needed for the project. Before being able to do so a Stage-Gate (SG1) form has to be submitted to the board, to gain approval before moving on to the next phase of the project.

This is called the **Acquisition** phase. Typically here the responsibility lies with LD, but the LA and LO are involved from the start to assess the suitability of the site for the proposed development. During the Due Diligence (DD) act, LD, LO and LA examine various aspects of the project, including financial, legal, technical, and environmental issues. The purpose of DD is to identify and evaluate any potential issues that could affect the success of the project and to make informed decisions about whether to proceed with the project or not. When continuing, the development team will work to create a sketch design (SO, "schets ontwerp") for the project, taking into account the findings of the due diligence process and any recommendations made in the report. This may involve working with architects and other design professionals to create a conceptual layout and mass study of the project, as well as determining the overall scope and scale of the project. The goal of this phase is to create a detailed design proposal, SG2, that can be used to secure funding and move forward with the project.

Next is the **Development** phase, consisting of the preliminary design (VO, "voorlopig ontwerp"), definitive design (DO, "definitief ontwerp") and the technical design (TO, "technisch ontwerp). During this phase, LD is still managing the project, by coordinating the teams for the delivery of the next stage gate and the external parties. The goal of the development phase is to further refine a deeper level of detail, to identify and mitigate risks as much as possible and develop the project concept that was established during the opportunity and acquisition phases. After DO the last SG3 is submitted including the final design of the project. One key difference between working on the development phase in a modular construction project versus a traditional construction project is that the design must be optimized for prefabrication and assembly. Projects of Lister Buildings aim to use a greater degree of standardization and repetition in the design by defining the set of modules beforehand and incorporating them in the mass study. This, however, has unfortunately due to circumstances not always been the case. At the end of the phase, close to TO, LM gets involved and takes on a larger role within the design process to take into account the capabilities of the manufacturing process and the available materials, as well as the logistics of transportation and assembly. By working closely with the manufacturing team during the development phase, the design team can ensure that the building can be manufactured efficiently and cost-effectively and that it can be assembled on-site with minimal disruptions to the construction schedule.

The **Realization** phase is the final stage of the development process and includes the execution design, production and assembly of the modules. The execution design (UO, "uitvoerings ontwerp"), is the detailed design used to construct the building. This design includes all the technical specifications and dimensions necessary for the production and assembly of the modules. The production phase involves the manufacture of the modules in a production factory, using the execution design as a guide. This phase also includes any necessary finishing work, such as the installation of electrical and plumbing systems The realization phase also includes the quality control and inspection of the building to ensure it meets all the required standards and specifications, before being stored at the end of the assembly line to await transportation to the onsite location for final building assembly.

7.4 Production process

In order to take the first step towards designing with standard modules, LA and LO had to establish a set of construction principles and solutions. For the construction system they use prefab 3D modules with 6 to 8 columns whenever possible, but they also use 2D parts to foster creative freedom. The 3D modules are constructed at the factory and 2D parts are added on-site. The system is completely demountable, bio-based dry-assembled, and future-proof throughout its life cycle. The timber is from partner Stora Enso who source their material from sustainable forests in Europe. The load-bearing columns allow for flexible placement when integrating the partition walls in the modules. This allows to create two, three, and four-room apartments. As the columns are load-bearing, the apartment's partition walls may be positioned for layout flexibility. The disadvantage is that the nodes must be structurally stronger, resulting in an increase in cost. Complete bathroom and kitchen modules are lifted inside the module. Each module consists of columns, a floor, and a ceiling, and may be subdivided freely inside the columns; The floor structure consists of a CLT slab, insulation, ballast, piping, and finishing. This total is also a bit thicker than traditional construction.

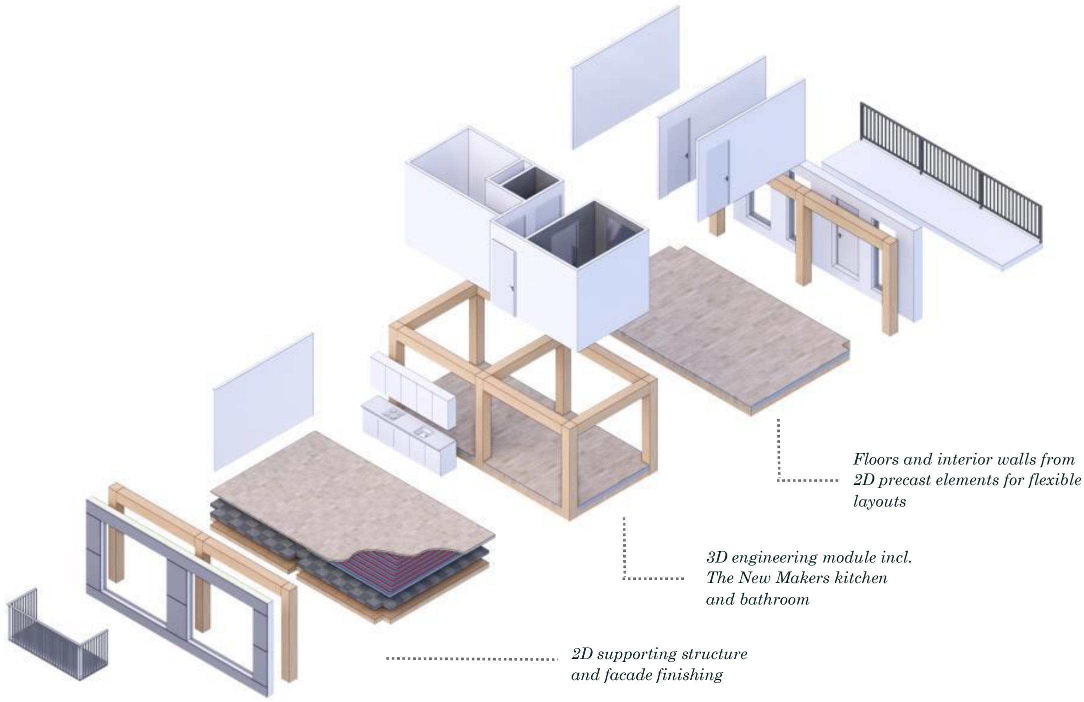

Figure 23. Module pack elements (Lister Buildings, 2022)

Scaling up the factory goes along with growth. Currently, the production is done manually, at some point it does pay off to automate but so far it is too high an investment.

Modular construction, particularly when utilizing wood-based materials such as Cross Laminated Timber (CLT), presents a unique set of design challenges. Lister Buildings has expressed that one of the main challenges is to find the balance between maintaining flexibility in design while ensuring that modules can be utilized without compromising aesthetic quality or freedom in facade design. Additionally, finding the right partners within the value chain, who possess the necessary vision, knowledge, and expertise in software integration and human qualities, has also been noted as crucial to their success. The design process must also be adapted to accommodate modular construction, which can be a significant hurdle, especially when working with relatively new materials like CLT. Furthermore, the relatively higher fixed costs for the R&D (for acoustics, fire safety and wind load) in order to construct wooden high-rise buildings and the need for constant production levels must be taken into account. Moreover, significant pre-investment is required in areas such as design, setting up the production facility with supply-chain management, and digitalization of the design and construction process.

With a few projects under the belt, Lister Building has learned that assembling 2D elements separately on-site is a very time-consuming and challenging task. They have also faced difficulties with external factors such as weather conditions. As a result, they have shifted their focus to maximum 3D assembly for future projects, alleviating LM with fewer unique features to take into account which makes it easier to set up assembly lines.

They also found that focusing on one-, two- and three-bedroom apartments is a more efficient approach as they have incorporated maisonettes in their current FITz project and implemented unique architectural designs for passages to add variety and break away from the repetition often associated with modular construction. Again this created a high design variety which negatively affected the production process as it has to produce a large and deviating set of modules, which is not beneficial in a production environment.

Tabel 7. Overview projects of Lister Buildings: Paviljoen, Milsbeek and FITz.

	Location	m2	No. App.	Floors	Developing term	Type
Paviljoen	Weert, NB	150	3	3	01/21 – 09/22	Hybrid
Milsbeek	Milsbeek, LB	1200	20	2	01/20 – 06/23	3D
FITz	Amsterdam, NH	4400	80	7	04/21 – 06/24	Hybrid

Also, the project has been experiencing some difficulties with the scaling of the projects. When analysing table 8 above, is shows a reasonable increase in no. of apartments per project. However, the complexity levels between the projects were significantly different. One of the main learnings from Lister's first few projects is that building smaller-scale structures, such as the Paviljoen, with its various unit types, did not allow for the assembly line to fully mature and achieve a streamlined and automated process. The Paviljoen was intended to serve as a pilot project to gain experience in assembling the modules, which could then be repeated in future projects. However, the Milsbeek project, which had a higher number of apartments, turned out to be less complex and relied more heavily on repetition, but not necessarily from the modules used in Paviljoen, resulting in the restructuring of the assembly lines at the production factory. The FITz project, Lister Buildings largest project, with its broad range of different modules and less repetition than the other two projects, proved again to be complex, highlighting the importance of finding the right balance between variety and repetition in modular construction.

7.4.1 Project – "Het Paviljoen"

This project represents the initial pilot undertaking in a three-phase validation of Lister Buildings' module construction concept. The building comprises three levels, with a one-bedroom apartment of 50 m2 on the ground floor, a two-bedroom apartment of 75 m2 on the first floor, and a lounge area on the top floor. This project served as a test bed for assessing the building's strength, vibrations, acoustics, fire safety, and airtightness.

The structure consists of six 3D modules that form the apartments, with staircases and the lounge area installed using 2D elements, making it a hybrid modular construction project. The building is entirely made of timber, including glulam columns and CLT floor plates, with steel cross bracing and timber single diagonal bracing to ensure stability. Multiple sustainable technologies were integrated to enhance the building's overall performance and create a comfortable and healthy living environment. The project was the result of close collaboration with partners such as cepezed and Pieters Bouwtechniek, as well as suppliers like CLTS and The New Makers.

Figure 24. "Paviljoen" floorplans (left: groundfloor, right: first floor) (Lister Buildings, 2022)

Lister Buildings encountered delays during their first project due to inaccurate planning estimates, which resulted in overlapping phases, such as design and procurement, and conflicting activities. This is a common challenge for new entrants to the modular construction industry, as the process requires a different approach to project management and supply chain coordination compared to traditional construction. Specifically, the use of offsite manufacturing and the integration of multiple supply chain partners require a high degree of coordination and communication. The resulting delays can impact the overall project timeline and increase costs. Therefore, it is important for modular construction firms to carefully plan and manage their projects, especially in the early stages, to ensure a successful outcome.

Figure 25. "Het Paviljoen" photo's – Front profile (left) and first floor (right). (Eva Bloem, 2022)

7.4.2 Project – "FITz"

After Milsbeek, the "FITz" project was the third pilot in the series to Proof the Concept of Lister Buildings. This project was tendered out in 2021 by the municipality of Amsterdam for a plot in the Amstelkwartier. The tender was won by Lister Buildings with a design of an apartment complex combined with a plinth for commercial purposes. The building consisted of seven levels including 70 apartments, ranging from 47 m2 to 108 m2.

FITz structurally consists of three wings and has no load-bearing facades at all. The building system and apartments consist of a combination of 2D and 3D elements and demountable nodes. This results in a system where, among other things, the facade can be removed in the future and replaced with another desired facade system. The bathrooms and kitchens are again supplied by The New Makers. The project's design was the result of collaborations with architectural bureau Mees Visser, urban developer U.Minds and landscape architect BOOM, as well as close suppliers like CLTS and The New Makers.

The implementation of the modular construction concept by Lister Building in this project has been dealing with some challenges, which have led to project delays. These challenges can be attributed to the limited experience of Lister Building in modular construction, as this is their first complex project. Additionally, the project has been affected by external factors such as an increasingly stressed construction market due to rising material costs and interest rates. These factors have led to delays and unforeseen complications in the implementation of the project. With the support of the municipality, Lister Building has been working with partners and suppliers to overcome these challenges and continue the successful implementation of the project. As a result, Lister Building had to modify the design of the project to a 2D construction project. Although this limited the company's ability to fully capitalize on the benefits of modular construction, it provided greater design flexibility, which was essential to adapt to the changing circumstances and ensure the success of the project.

Figure 26. "FITz" renders – Side profile (left) and from the courtyard (right). (Lister Architecture & Mees Visser, 2021)

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Source: Lister

8

Results & Analysis

8. Results & Analysis

This chapter presents the results from the interviews conducted with the employees of Lister Buildings. The data gathered in both the qualitative and quantitative parts of the interviews is analyzed to identify the gaps between the current and desired production systems, explore the role of coordinators in each phase, and develop a list of critical success factors for enabling vertical integration in the modular construction industry. These results are structured to align with the methodology and scope stated in Chapter 3. The relevant quotes have been gathered by decoding the transcripts. The results are presented in subchapters that align with the methodology and scope outlined in Chapter 3. Relevant quotes from the interviews are used to support the analysis. The visualizations are based on careful analysis of data that is gathered from the interviews and the additional interactive questions.

8.1 Production systems

In this subchapter, the focus is on the analysis of the quantitative data collected through the conducted interviews with the employees of Lister Buildings. The subchapter is divided into two parts, namely "Company Profiles" and "Department Profiles". The first part, "Company Profiles", provides an overview of the raw data which is used to identify the current and desired production system of Lister Buildings. The second part, "Department Profiles", analyses the discrepancies between the company profiles to understand the shifts in the profiles and the reasons for these shifts. This analysis is done per department. Overall, the subchapter aims to provide insights into the production systems of Lister Buildings and identify areas for improvement.

Figure 27. Color scheme of for Production System analysis (o.i., 2022)

8.1.1 Company Profiles: Current and Desired Production System

Lister Buildings at present

		LD			LA			LO		LM		
		#1	#2	#3	#1	#2	#3	#1	#2	#1	#2	#3
Organization	Driver	-2	0	2	-2	0	-1	-1	0	0	-1	-1
	Innovation	0	-2	-1	-2	-1	-1	-2	1	0	-1	0
	Focus perspective	-1	0	-1	-1	1	0	-1	-1	-2	-1	-2
	Internal team set-up	1	1	1	0	1	1	-1	2	0	0	1
	Organisation set-up	0	1	-1	-1	0	0	-1	-1	-2	-1	1
Product	Design Type	-1	-2	-2	-1	-1	0	-2	-1	-2	-1	-1
	Client input	1	0	-1	-1	-1	0	-2	-1	0	0	1
	Design variety	0	0	-1	0	0	0	-1	1	-2	-1	-1
	Product configuration	-1	-2	0	-1	1	-1	-1	-1	-2	-1	-1
	Profit margin	2	2	2	2	2	1	-1	-1	0	2	2
Production	Production rate	-2	-2	-2	-1	-1	-2	-2	-1	-2	-2	-1
	Production type	1	-1	0	-1	1	0	-1	-1	-2	-1	1
	Supply chain	1	-1	-1	-1	1	0	-2	0	-1	0	1
	Delivery time	-1	0	-1	-2	0	-1	-2	0	-2	-1	0
	Strategy	1	-1	-1	0	0	0	-1	1	2	0	0
	External relations	1	2	-1	1	-1	0	-1	1	0	0	1

Figure 28. Company level – Lister Buildings "present" profile (o.i., 2022)

At first glance, the table does not convey one consistent production system, however, does appear in the white/blue spectrum, indicating a project-based environment. There is one characteristic with an opposite colour display which is the Profit Margin. Green colours define an approach leaning towards the product, which elaborates in having currently a low-margin per module. The results from the individuals are analysed to acquire the results on a departmental level. These show a range of leaning towards the project/design side of the spectrum, such as engineer-to-order and make-to-order. There is a noticeable difference between LD & LA and LO & LM, as the latter profiles show more resembling colours to the product-based environment.

"Production rate", "design type" and **"product configuration"** display the current state with a more project approach, which resembles more to the concept-to-order and engineer-to-order. Whilst, **"Profit margin"**, **"internal team set up"** and **"external relations"** are displaying colours linked to a product approach, meaning that these characteristics resembled features make-to-order and assembly-to-order.

> *"We merely do things this way for the time being since we can't ramp up as quickly as we'd want. Growing into the Manufacturing process takes time, and you must have volume if you wish to run larger production. Otherwise, you'll remain stuck with one-of-a-kind projects."* ***- Manufacturer***

This suggests that interviewees see the current production system as heavily focused on project-based approaches, with low emphasis on **"production rate'**, **"design type",** and '**product configuration"**. This may indicate that the organization places a greater priority on delivering unique, one-off projects that are tailored to the specific needs of the client. On the other hand, **"Profit margin", "Internal team set up"** and **"External relations"** scored higher, indicating that the organization places a greater emphasis on these characteristics, which are typically associated with product-based approaches. These characteristics, such as having a long-term internal team structure, strong external relationships with suppliers and partners, as well as a focus on efficiency and cost-effectiveness, suggest that the organization places a significant emphasis on profitability in its production process.

Based on these results from the questionnaire, the employees of Lister Buildings currently view their production system as one that resides slightly on the project environment, being **between ETO and MTO**. These are characterized by low-volume production, producing a highly customizable product with low repetition, which almost resembles a one-of-a-kind product. This lack of standardization in their product makes it difficult for them to gain control over the variations in their production process. Additionally, they currently have a low-profit margin per module, which can be attributed to several factors. They rely on the use of long-term teams for their projects, as the company operates as a semi-integrated entity. Furthermore, they have reasonably close relationships with the suppliers of the elements that are used in their building modules.

Lister Buildings in the future

		LD			LA			LO		LM		
		#1	#2	#3	#1	#2	#3	#1	#2	#1	#2	#3
Organization	Driver	0	2	2	2	2	0	0	-1	0	0	1
	Innovation	-1	0	1	0	2	1	2	-2	2	2	2
	Focus perspective	0	0	0	0	0	0	0	0	0	1	1
	Internal team set-up	-1	2	-1	2	2	1	2	2	2	2	2
	Organisation set-up	2	2	1	2	1	-1	1	2	2	1	2
Product	Design Type	1	0	2	0	2	2	-1	1	1	1	2
	Client input	1	0	0	1	1	0	-1	-1	0	1	1
	Design variety	0	0	-1	1	-1	-1	-1	1	2	1	0
	Product configuration	2	2	1	2	2	2	2	2	2	1	2
	Profit margin	2	-1	1	-1	-2	-2	1	-1	-2	-2	0
Production	Production rate	2	2	2	1	2	1	1	2	2	2	2
	Production type	1	2	1	1	2	2	1	2	1	1	2
	Supply chain	2	1	2	1	2	2	1	2	2	2	2
	Delivery time	2	2	2	0	2	1	1	2	2	2	2
	Strategy	0	2	1	1	1	0	0	0	2	2	2
	External relations	2	2	1	2	2	1	2	2	2	2	2

Figure 29. Company level – Lister Buildings "future" profile (o.i., 2022)

First of all, it is clear from the comparison of the previous image to the current one that there is a significant change in overall colour. The new image shows a predominance of green, indicating a shift towards a more product-based approach for the production of modular units, however the Organization and Product categories appear more neutral and light-red, indicating a mix of project- and product approach. Also, and again, "profit margin" colours in contradicting colours than in the display, relating to a more project-definition to is: high-profit per module. Overall, this might suggest a focus on increasing efficiency, streamlining the production process, and improving profitability while still being able to accommodate unique client needs.

> *"For Lister, too much standardization can limit our flexibility and creativity. While standardization can improve production efficiency, It's important to have a balance between that and customization."* ***– Developer***

The departmental results of the follow-up questionnaire indicate a clear consensus among the different departments about their future vision. The display of the results depict a strong shift towards the product-oriented side of the spectrum, point to an assembly-to-order production system. This means that there is a shared belief among the departments that the organization should focus on improving efficiency, streamlining the production process, and increasing profitability while still being able to customize the product to meet unique customer needs.

Next, it is of importance to explore the different production systems linked to the characteristic. The future expected form of Lister Buildings scored the highest points for **"product configuration", "external relations", "production rate"** and **"supply chain"**. These results link towards the extreme production system of make-to-stock. Additionally, the lowest points calculated for **"profit margin", "design variety"** and **"focus perspective"**, are similar to make-to-order characteristics.

This analysis shows that the vision of Lister Buildings is centred on a production system that emphasizes high-volume production and standardization of product designs. The high scores suggest that the organization aims to streamline their production process to improve efficiency. The low scores reveal that the organization strives for a high-volume production system over customization and unique customer needs. The organization might be looking for a balance between both, having a standard product and still being able to adapt to clients' needs.

In summary, Lister Buildings, as viewed by its employees, sees its future production system as one that prioritizes the control of variation. This means that they aim to control the range of configurations by engineering and predefining the design specifications of the different modules. One of the key advantages of controlling variation in modular construction is that it can make it easier to achieve high-volume production, which the company plans to pursue to reach its potential for high-profit margins per module. Lister Buildings also aims to establish sustainable relationships with suppliers to ensure a stable and reliable supply chain, improving the production process. In addition, the company still wishes to provide some level of customization to meet client requirements within fixed design parameters. Another key aspect of the company's future vision is a balance in decision-making between the developer/designer and manufacturer, as both are considered equally important and contribute equally to the project. Given the importance of the system engineer in modular construction projects, it is likely that Lister Buildings would also consider them to be an important contributor to the project and seek to balance their input with that of the developer/designer and manufacturer. However, this would need to be confirmed through the qualitative research of this study. Overall, the shift is towards a more product-based environment, similar to an **ATO** production system.

8.1.2 Department profiles: Identifying Shifts

This section of the analysis focuses on identifying the shifts that occurred within departments from the current to the desired production system. The shift in profiles is analyzed in the context of the company profiles presented in the previous subchapter to identify the reasons behind the shifts. By understanding the shifts in the production system, the subchapter aims to provide insights into the areas that require improvement at the departmental level. The analysis will be presented using various visual aids, including graphs and charts, to provide a clear understanding of the shifts that occurred. Table 8 provides an overview of the raw data obtained from the two previous tables.

		Lister Development									Lister Achitecture								
		#1			#2			#3			#1			#2			#3		
		LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△
Organization	Driver	-2	0	2	0	2	2	2	2	0	-2	2	4	0	2	2	-1	0	1
	Innovation	0	-1	-1	-2	0	2	-1	1	2	-2	0	2	-1	2	3	-1	1	2
	Focus perspective	-1	0	1	0	0	0	-1	0	1	-1	0	1	1	0	-1	0	0	0
	Internal team set-up	1	-1	-2	1	2	1	1	-1	-2	0	2	2	1	2	1	1	1	0
	Organisation set-up	0	2	2	1	2	1	-1	1	2	-1	2	3	0	1	1	0	-1	-1
Product	Design Type	-1	1	2	-2	0	2	-2	2	4	-1	0	1	-1	2	3	0	2	2
	Client input	1	1	0	0	0	0	-1	0	1	-1	1	2	-1	1	2	0	0	0
	Design variety	0	0	0	0	0	0	-1	-1	0	0	1	1	0	-1	-1	0	-1	-1
	Product configuration	-1	2	3	-2	2	4	0	1	1	-1	2	3	1	2	1	-1	2	3
	Profit margin	2	2	0	2	-1	-3	2	1	-1	2	-1	-3	2	-2	-4	1	-2	-3
Production	Production rate	-2	2	4	-2	2	4	-2	2	4	-1	1	2	-1	2	3	-2	1	3
	Production type	1	1	0	-1	2	3	0	1	1	-1	1	2	1	2	1	0	2	2
	Supply chain	1	2	1	-1	1	2	-1	2	3	-1	1	2	1	2	1	0	2	2
	Delivery time	-1	2	3	0	2	2	-1	2	3	-2	0	2	0	2	2	-1	1	2
	Strategy	1	0	-1	-1	2	3	-1	1	2	0	1	1	0	1	1	0	0	0
	External relations	1	2	1	2	2	0	-1	1	2	1	2	1	-1	2	3	0	1	1

		Lister System Engineering						Lister Manufacturing								
		#1			#2			#1			#2			#3		
		LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△
Organization	Driver	-1	0	1	0	-1	-1	0	0	0	-1	0	1	-1	1	2
	Innovation	-2	2	4	1	-2	-3	0	2	2	-1	2	3	0	2	2
	Focus perspective	-1	0	1	-1	0	1	-2	0	2	-1	1	2	-2	1	3
	Internal team set-up	-1	2	3	2	2	0	0	2	2	0	2	2	1	2	1
	Organisation set-up	-1	1	2	-1	2	3	-2	2	4	-1	1	2	1	2	1
Product	Design Type	-2	-1	1	-1	1	2	-2	1	3	-1	1	2	-1	2	3
	Client input	-2	-1	1	-1	-1	0	0	0	0	0	1	1	1	1	0
	Design variety	-1	-1	0	1	1	0	-2	2	4	-1	1	2	-1	0	1
	Product configuration	-1	2	3	-1	2	3	-2	2	4	-1	1	2	-1	2	3
	Profit margin	-1	1	2	-1	-1	0	0	-2	-2	2	-2	-4	2	0	-2
Production	Production rate	-2	1	3	-1	2	3	-2	2	4	-2	2	4	-1	2	3
	Production type	-1	1	2	-1	2	3	-2	1	3	-1	1	2	1	2	1
	Supply chain	-2	1	3	0	2	2	-1	2	3	0	2	2	1	2	1
	Delivery time	-2	1	3	0	2	2	-2	2	4	-1	2	3	0	2	2
	Strategy	-1	0	1	1	0	-1	2	2	0	0	2	2	0	2	2
	External relations	-1	2	3	1	2	1	0	2	2	0	2	2	1	2	1

Table 8. Department results and delta's. (o.i., 2023)

A new column called "delta" [Δ] has been included in the table, which represents the extent to which the *current* production system deviates from the *future* production system. The larger the score in the delta column, the greater the discrepancy between the perceptions of the current and future production system. In addition, a negative delta suggests a change from a higher number to a lower number, while a positive delta indicates a change from a lower number to a higher number. A significant positive or negative delta implies a change in that characteristic towards a product-based or project-based environment, respectively. A small delta indicates little or no change between the current production system and the desired future state for that specific characteristic. By examining the delta column, it's possible to identify the areas that need to be addressed to bring the production system in line with the ideal or future profile.

Next, the raw data has been visualized in a landscape contour map. The map displays the differences, or "delta's," between the current and future production system profiles. The legend uses the colours blue and green to represent the project and product approaches, respectively.

The map has the characteristics listed on the horizontal axis and the interviewees per department listed on the vertical axis. Each interviewee is identified by a code consisting of a department abbreviation and a number, such as "LD1" which refers to the first interviewee in the Lister Development department. For a alternative raw delta's visualisation, see Appendix F.

Figure 30. Color scheme for delta's bandwidth (o.i., 2023)

Lister Development

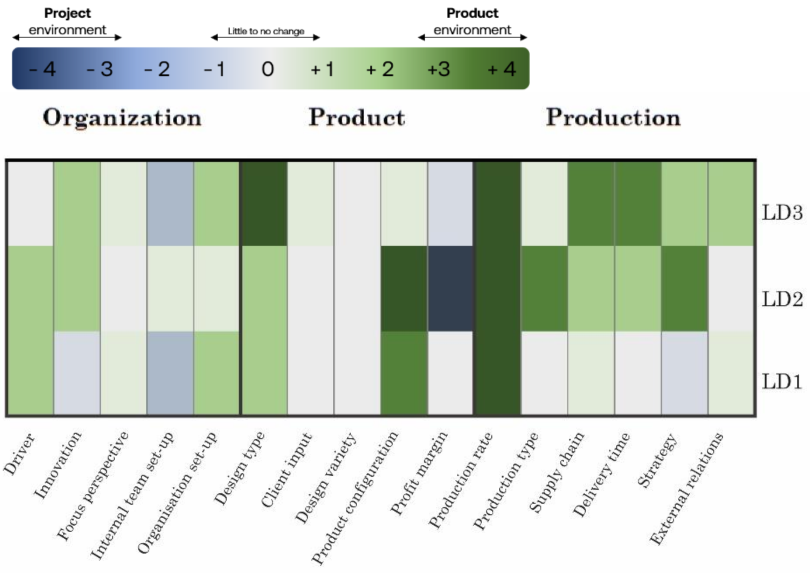

Figure 31. Lister Development - discrepancies between "present" & "future" profiles (o.i., 2022)

The visual representation of the data provided by the employees of LD shows large positive concentrations around **"design type", "production configuration", "production rate", and "delivery time".** The desire to work with standardized elements is likely driven by the need to have better control over the different possible configurations, which would lead to an increased production rate and, as a result, quicker delivery times.

> *"In my perfect world, developers would have a clear understanding of the design and implementation principles for a project before they start working on it. This would make the development process much more efficient."* **- Developer**

> *"When it comes to manufacturing, we should focus on standardizing processes at the front end, such as LD, LO, and LA. This would lead to lower production costs, increased productivity, faster production times, and ultimately lower costs for the end product."* **- Developer**

On the other hand, the white spaces observed around **"focus perspective", "client input",** and **"design variety"** indicate that there is limited to no need for change in these areas according to the Development employees. From their point of view, this suggests that Lister Building's current approach to these areas is in line with their future desired operating profile.

> *"At the module level, the developer may have less influence on the process, but at the building level, the developer plays a significant role. Ideally, we want the developer to have minimal input on the product/module once it's finalized, but ultimately, the entire building must come together as a cohesive system. This is where a skilled system architect or project manager can play a critical role in ensuring success."* ***- Developer***

When reviewing the raw data of LD, the "focus perspective" shows their belief in having a good balance between the design and make side. This could suggest that LD view the decision weight as well-balanced between the designers/developers and production team, which aligns well with their future goals.

Similarly, the score of "client input" indicates that the current level of involvement of clients in the design process should remain the same, suggesting that Lister Building's current approach to client engagement is in line with their future goals. "Design variety" leans a bit towards the project approach, meaning a desire for LD of higher design freedom incorporated in the module's design. This suggests that the developers agree that the company's current design approach allows for a good degree of flexibility and adaptability to unique client specifications.

> *"As a design firm, we value the freedom to create innovative designs, while builders may prioritize consistency and efficiency. Finding a balance between these perspectives can be a challenge, but it's important to have an acquisition strategy that doesn't deviate too much."* ***- Developer***

Lastly, the grey areas indicate a negative delta, meaning a shift towards a more project-related context which is to be seen in **"Internal Team Set-up" and "Profit Margin".** Interestingly, LD is the only department that displays a preference for short-term collaboration within internal teams which could indicate that they may have a different approach or opinion on how teams should work together compared to the other departments. The significance of this is that it highlights potential differences in departmental culture, priorities, and values, which could affect how the company functions and how successful it is in achieving its goals. Understanding these differences can help the company identify areas for improvement and develop strategies to foster better collaboration and communication across teams.

The discrepancy in the "Profit Margin" suggests that the company is considering ways to improve efficiency and cost-effectiveness in their product design and production processes in order to increase the profit margin per module, while still meeting the unique needs of clients.

Lister Architecture

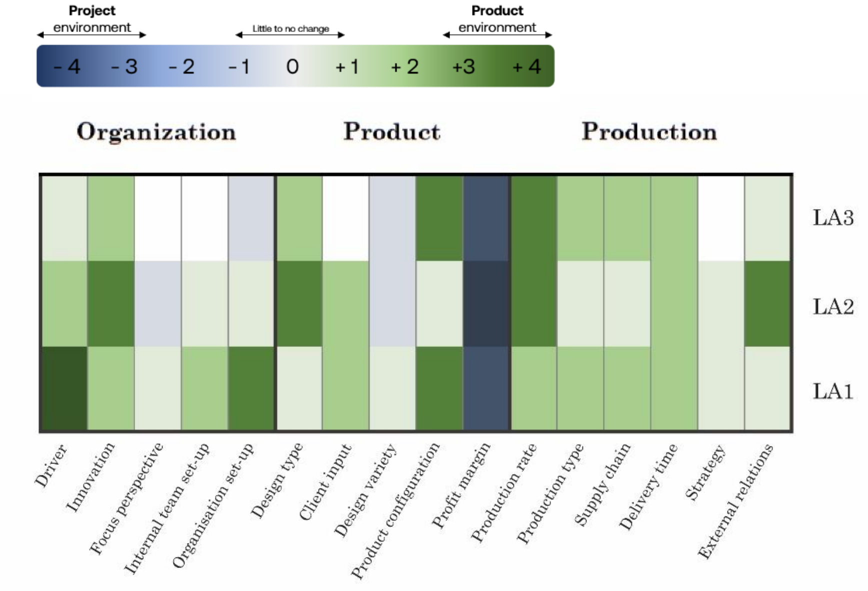

Figure 32. Lister Architecture - discrepancies between “present” & "future" profiles (o.i., 2022)

The data collected from employees at LA has been visualized in the form of a graph, with positive concentrations of results observed **“Design Type”, “Product Configuration” and "Production Rate"** categories, similar to LD. From the perspective of architects, the importance of having control over various configuration possibilities is evident, with a positive delta indicating a shift towards a more product-oriented approach. This could imply that, in their belief, using standardized components that can be configured in various ways will meet a wide range of needs and demands.

Additionally, the high concentration in the "Production Rate" category implies that the company is prioritizing product-oriented characteristics, such as high production volumes and a consistent flow of production.

> *“In the past, we didn't approach projects in a systematic way, and often treated them as unique, one-off endeavours. This approach made sense at the time, given that we didn't have a well-established principles or design specifications in place. However, we now have a better idea of what our system should look like, even if it's not quite ready yet. As a result, we are making an effort to use a more systematic approach moving forward.”* ***- Architect***

The lower deltas were observed in the **"Focus Perspective" and "Design Variety",** categories, indicating that the company currently embodies their desired characteristics in these areas. This suggests that, from the perspective of LA, the balance of decision-making power is currently evenly distributed between the development, design, and production teams. Additionally, the data suggests that the company has a production strategy focused on an efficient lean approach, and design variety leaning towards the project-domain, indicating that the architects want to foster more design freedom in the future of Lister Buildings.

> *“It would be really helpful for us on the LO side if we're given those building blocks upfront. That way, we can focus on dealing with the 20% design variation, and not worry about the rest.”* ***- Architect***

Lister System Engineering

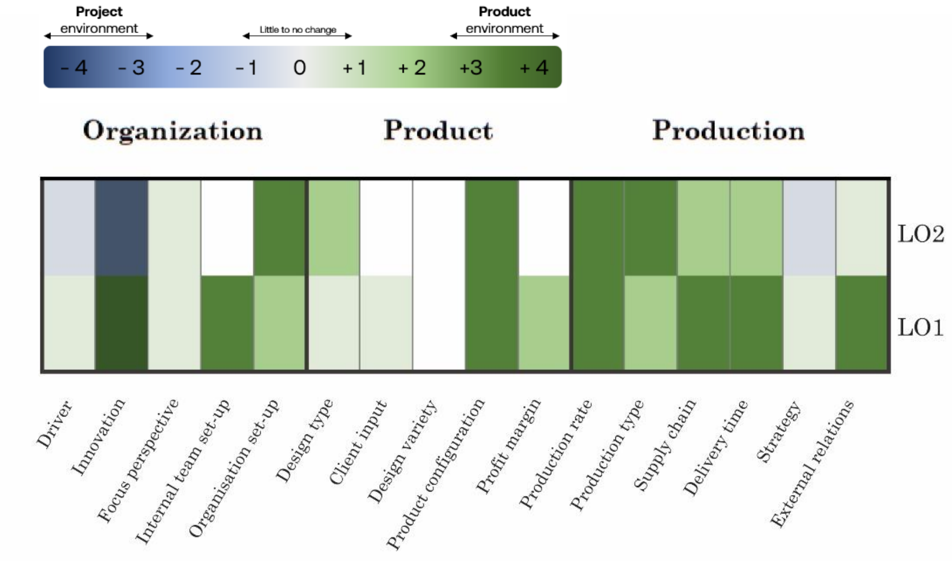

Figure 33. Lister System Engineering - discrepancies between "present" & "future" profiles (o.i., 2022)

The data collected from the employees of LO suggests that there are significant differences in the areas of **"Innovation".** "Innovation" is a key area of focus for LO, as they are responsible for introducing new ideas and making improvements to the modules. However, it appears that this is not as high of a priority for other departments within the company. The data shows a high discrepancy in this area, however, the participants have conflicting perspectives on the goal of innovation. One perspective leans more towards adapting to market changes, while the other is more focused on continuous innovation based on customer satisfaction.

> *"What I've noticed is that the installation and construction phase is often a big challenge for our projects. There are a lot of interconnected components and bottlenecks that we need to navigate. It can be overwhelming at times, but there's definitely room for improvement and progress."* ***– System Engineer***

Notably, there is also a broad area of positive shifts within the production category, which may indicate that LO has a significant impact on the production factors that influence the production system. For example, the data suggests that the company aims to move towards a more product-oriented approach, as indicated by a high delta in the "**Product Configuration", "Production Rate**", **"Production Type", "Supply Chain" and "Delivery Time"** categories. Similarly to LD and LA, their view suggests that gaining control of the product configuration, by working with standardized elements would work beneficial to shaping the production type to an up-tempo continuous assembly line.

> *"I believe that we should focus more on the manufacturability and logistics of our production processes. As a team, we could play a bigger role in designing products that are easier to produce and transport. That's something we can definitely work on and improve."* ***– System Engineer***

Additionally, the data suggest that LO views the integration of the supply chain into the production system as a key area for improvement, and may be well-suited to take ownership and work towards this goal.

> *"There seems to be a disconnect between LM and LO, where each team blames the other for not being involved enough. But I think we, in LO, can help integrate and align these teams better. We have the potential to make a real difference in this area."* ***– System Engineer***

Lastly, the data shows negative discrepancies in the areas of **“Client Input”** and **“Design Variety”.** The first indicates that the employees of LO are satisfied with the current level of client involvement in the design process. The data suggests that the design variety is not a major area of concern, although there is some misalignment internally as to what this would mean for Lister Buildings, with some leaning more towards a project-oriented approach and others towards a product-oriented approach. This could mean that there is some uncertainty about the level of standardization that should be applied in the design of the modules.

Lister Manufacturing

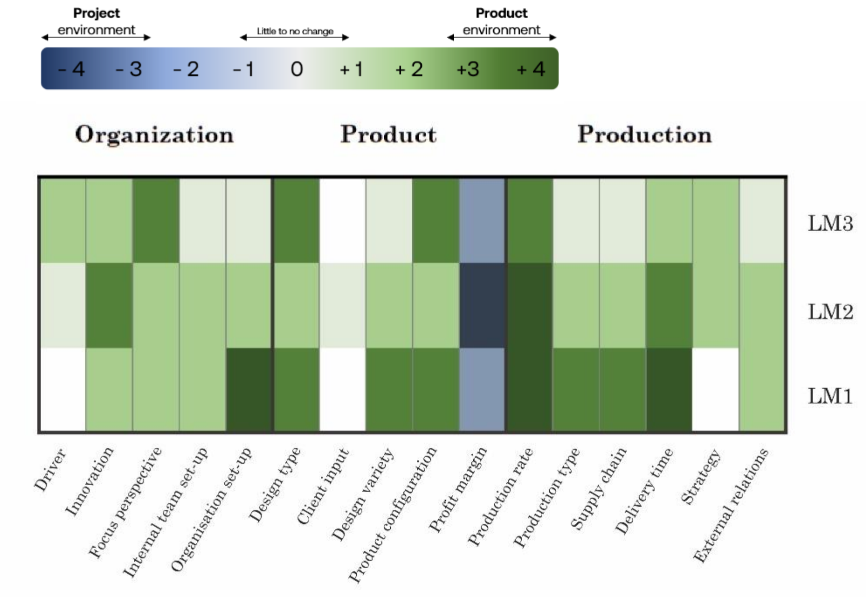

Figure 34. Lister Manufacturing - discrepancies between “present” & "future" profiles (o.i., 2022)

Out of all departments, LM has the most saturated visual display of the discrepancies between the present and future production system profile of Lister Buildings, depicted in figure 34. This might imply various things, either the team is more critical of the differences or it might be due to being closely involved with or accountable for aspects of the production system as the manufacturer of the modules, making it a crucial player in the collaboration within the value chain. The most significant change towards a product approach is observed at **“Production Configuration”, “Production Rate”, “Design Type”, and “Delivery Time”.** Looking at the incentive structure for different departments related to the characteristics, it is likely that only LM is accountable for the production rate and delivery time.

> *"In my experience, the projects we're working on right now aren't quite up to the standard production we're aiming for. This presents both opportunities and challenges. It's important to focus on the problems we can identify, but we should also be looking for ways to improve through practice and standardization. By creating a standard product, we can streamline our processes and make improvements more quickly."* ***- Manufacturer***

The data relating to **"Focus Perspective"** reveals an interesting discrepancy, with the manufacturing team feeling that the current decision-making weight is on the side of designers and developers. This perspective is in slight conflict with the desired outcome of the LD and LA teams, as they had expressed a current situation of a balanced decision-making process. It is possible that either the current decision weight has been falsely conveyed by LD and LA, or that LM desires a greater influence on the decision-making process than LD and LA.

> *"One area where I think we could improve is communication between different teams within our organization. Too often, designs are created without taking into account the practicalities of manufacturing, which leads to frustration and delays. It's important that we have a better understanding of each other's processes and communicate more effectively to avoid these issues."* ***- Manufacturer***

> *"In the SO phase, LO has a more advisory role, while LM is responsible for making the products. I think you can achieve better results if you working closely with the person who will be making the product."* ***- Manufacturer***

The lower score mentionable is the **“Client Input”,** surprisingly, as this indicates that also LM supports the idea of giving the client freedom for input, in comparison to traditional manufacturing industries, which risks leading to more variation and more unique projects. However, it could be because the team believes that giving clients more involved in the design process leads to a more satisfactory end product for the client, which in turn could lead to increased customer satisfaction and potentially repeat business. **“Profit Margin”** has been elaborated on previously, and just as the other departments, LM want to increase the profit per manufactured module.

Conclusion

The majority of the data suggest that all departments aim to shift to a more product-approach in the characteristics of “**Design Type”, “Production Configuration**”, **“Production Rate”,** and **"Delivery Time"** to improve its production processes in order to increase efficiency and profitability. This may involve making trade-offs between customization and scalability, as well as balancing between product quality and delivery times. Currently, the departments are struggling with variations in product designs, long delivery times, and producing one-of-a-kind products. However, they are determined to overcome these challenges and move towards a more standardized, efficient, and profitable production environment. It is important to note that all departments have deemed these factors to be of importance, indicating a company-wide commitment to improving production processes.

However, there are differences in the other categories, such as LO’s data not aligning internally on the goal of innovation and its significant impact on production factors. LD and LA have lower deltas in **“Focus Perspective”** indicating that the current approach to these areas aligns with their desired future operating profile, which they experience as a balanced between themselves and LM, whilst LM has a different view on that. **“Design variety”** is also in conflict with the different departments as LD, LA and LO’s data argues towards a balance between standardization but imbedding enough design freedom to cater to the clients need, whilst LM data suggesting that this variety take a more limiting range of standardized element. All departments show a significant discrepancy in the **“Profit Margin”** category, indicating that improving efficiency and cost-effectiveness is a priority for increasing profits per module.

Overall, the current Production System profile resembles the form between engineer-to-order and make-to-order with the data for future profile suggesting a shift towards a more product-based approach, leaning more into make-to-order and assemble-to-order production systems.

8.2 Coordination & Collaboration

The following interactive exercise focused on the systematic structure of Lister Buildings' collaboration, communication, and coordination.

In figure 33, we can see a visual representation of the importance of the involvement of different departments during different phases of the project as perceived by the other departments. This allows us to identify which department is responsible for driving the project during each phase and where the transfer of responsibilities occurs between different departments. The black blocks in the figure indicate areas where there is a perceived equal level of involvement by two departments.

		LD			LA			LO		LM						
		#1	#2	#3	#1	#2	#3	#1	#2	#1	#2	#3	LD	LA	LO	LM
SO	1	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	LD	**100%**	0%	0%	0%
	2	LO	LA	LA	LO	LA	LA	LA	LA	LO	LA	LO	0%	55%	**64%**	0%
	3	LA	LO	LO	LA	LO	LO	LO	LO	LA	X	LA	0%	**64%**	55%	0%
	4	LM	LM	LM	LM	LM	LM	LM	LM	LM	LM	LM	0%	0%	0%	**100%**
VO	1	LD	LD	LD	LD	LA	LD	LA	LA	LA	LA	LD	55%	**64%**	0%	0%
	2	LA	LA	LA	LA	LD	LA	LD	LD	LO	LD	LA	**55%**	55%	9%	0%
	3	LM	LO	LO	LO	LM	LO	LO	LO	LM	X	LM	0	18%	**55%**	36%
	4	LO	LM	LM	LM	LO	LM	LM	LM	LD	LM	LO	9%	0%	27%	**64%**
DO	1	LD	LD	LD	LA	LA	LA	LA	LA	LA	LA	LA	36%	**73%**	0%	0%
	2	LM	LO	LA	LD	LD	LD	LD	LO	LO	LD	LD	**55%**	9%	36%	9%
	3	LA	LM	LO	LM	LM	LM	LM	LM	LM	X	LM	0%	9%	9%	**73%**
	4	LO	LA	LM	LO	LO	LO	LO	LD	LD	LM	LO	18%	9%	**36%**	18%
TO	1	LD	LM	LM	LM	LA	LA	LA	LM	LA	LM	LA	9%	45%	0%	**55%**
	2	LM	LD	LA	LA	LM	LM	LM	LA	LM	LA	LM	9%	**55%**	0%	55%
	3	LA	LA	LO	LO	LD	LD	LD	LO	LO	X	LD	**36%**	36%	36%	0%
	4	LO	LO	LD	LD	LO	LO	LO	LD	LM	LD	LO	36%	0%	**55%**	0%

Figure 36. Results project coordinator (SO-TO), (o.i., 2022)

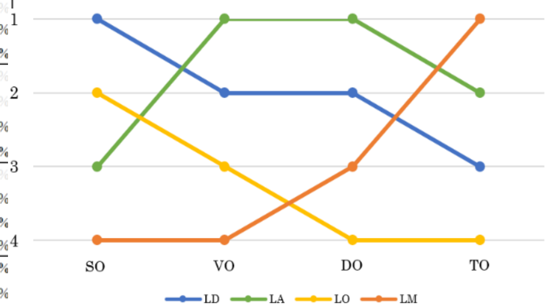

Figure 35. Plotted results (o.i., 2022)

SO

The SO of a modular construction project is the initial stage of the project, where the overall idea for the project is developed and refined. In this phase, a feasibility study is conducted to determine the overall scope and objectives of the project, including the design and layout of the modular units, the materials and technologies to be used, and the budget and timeline for the project. Other activities that may take place during this phase include researching and evaluating different design options and developing initial sketches and renderings.

At first glance, it is visibly in the first row that Development is homogeneously perceived as the carrier of the project during the SO phase. Full saturation - referring to a score of 100%, indicating complete agreement among all interviewees - is only detected in the SO phase and not in the other phases. This suggests that there is a shared understanding among the parties involved in the project about how responsibilities, tasks, and leadership should be allocated during this phase. The carrier is responsible for leading and guiding the project through the design and development stage, which is known as the SO, VO and DO phases. This would include determining the overall goals and objectives of the project, developing a concept design that aligns with those goals, and working with other departments and stakeholders to ensure that the design meets the needs of the project requirements. The carrier is responsible for leading the project through the initial design and planning stages and working closely with other departments to ensure that the project stays on track and on budget. Followed by close LO, LA and eventually LM.

VO

The carrier in the VO phase of the project, as identified by the participants in this study, is LA. This phase involves a significant amount of coordination between different departments and LA is seen as the primary department leading these efforts. LD transfers responsibility to LA and LO takes on a supportive role and LM holds still on the background. However, the close ranking of the number 1 and 2 indicate a lack of clarity in leadership and coordination. Furthermore, the combination of shared positions, indicated with the black box, between LA and LO occurs frequently from the derived employee data. This could indicate that these departments work close together in an integrated collaborative structure or that the alignment of responsibilities and expectations is lacking, resulting in an undefined organizational structure.

DO

Next, in the DO phase, as there is a more defined design of the project LO supporting role turns into an advising role, as the design is, as much as possible, frozen. Innovations or other adjustments are being reserved for the next project. Thereto, as the project is moving towards TO, it is essential for LM to be involved, preferably as soon as possible but in Lister Buildings case it is after the VO-design. LA is still the main carrier of this phase of the project

TO

Lastly the TO phase of a modular construction project, the focus is typically on the technical design of the building. This includes determining the specific components and materials that will be used in the construction, as well as the layout and engineering of the structure. This phase also involves developing detailed plans, architectural and engineering drawings and bills of materials. The aim of this phase is to create a detailed and accurate design that can be used to guide the construction process and ensure that the final building meets all relevant codes and standards. It is also an important phase to ensure that the building can be manufactured and assembled efficiently and that it will be able to perform as intended in terms of energy and other factors. Therefore, the involvement of LM is essential. Fortunately, LM is seen as the main carrier by the participants in the study, meaning that Lister Manufacturing is considered to have the most involvement during this phase of the project by other departments. The Technical Design (TO) phase indicate a transfer of responsibility and involvement from LA to LM as the project progresses. Additionally, the close ties of some departments in some phases suggest that in these stages the specific department is not seen as a more important carrier but the importance is split and shared by multiple departments, showing collaboration.

Figure 36 visualises how the responsibilities of the departments are digressing over the different phases throughout the project. Every party has been nominated as the carrier of the project, except for LO. This could mean that the role of LO is not considered central in carrying out the project during the different phases of the modular construction process, according to the perception of the participants in this study. It's important to note, this does not mean that the department is not essential to the project, however, the department isn't seen as the main carrier of the project, for example, LD is seen as the carrier in SO, LA in VO and DO and LM in TO. It could also mean that the role of LO is considered less essential in the developing management and execution phases, and is more focused on product management in design & engineering aspects. Additionally, it may also indicate that the responsibilities and involvement of LO are more closely tied to other departments, such as LD and LM, rather than being a standalone entity in terms of project management.

Conclusion

Based on the results from the exercise, it appears that there is a lack of clarity among the participants when it comes to the perception of which department carrying the most responsibility during each phase of the project, which is seen in figure 33b. SO is the sole phase where there is some sort of clear understanding as LD is seen as the primary carrier, leading with 100% of the votes. From VO on, there is a spread in the saturation which grows further in DO which reduces again in the TO phase. It is noteworthy that during the department of Development (LD) holds the belief that they are the primary driver of the project throughout its entirety. However, the other departments appear to hold a different opinion, with LA leading during DO and VO, and LM finally taking over the responsibility of the project in TO.

8.3 CSFs for Value Chain Integration

The purpose of this chapter is to provide a thorough examination and analysis of the qualitative part of the interviews. The methodology used is described in steps 4 – 6 in chapter 3.3.3.

Step 4 included the *transcribing and coding* with the preliminary list of CSFs to give structure to the qualitative raw data. This helps to uncover and understand the experiences, benefits, and challenges that participants encountered in regard to the integration of the value chain in a modular construction project. Meticulousness is crucial when undertaking this process, as close attention should be paid to the data to avoid overlooking any relevant information. The process is looped and iterated to ensure that the data is coded accurately with the appropriate Critical Success Factor (CSF). Quotes that would not fit into any CSF were set aside for later analysis. The final results of this step are to be found in Appendix E.

Next, in step 5, the *coded text was categorically analysed per CSF*. It is worth noting that the labels "Synergy," "Competency," and "Organization" were predetermined classifications that were used in the analysis. The categories within each label were pre-established, but due to the context validity of the CSFs, they were subject to modification depending on changes that occurred during the analysis. As a result of this process CSFs that were not or less frequently mentioned were eliminated and new CSFs were identified, which are highlighted in green in table below. These factors were frequently mentioned by the participants during the interviews and were subsequently researched for relevance and substantiation.

The study carefully analysed all the critical success factors (CSFs) in step 6, and provided a detailed breakdown of each factor, including newly defined CSFs with their substantiating literature, are elaborated in Appendix H. After identifying the CSFs, the study was able to redefine the Categories, and the final list is presented in Table 9. Using this list, the study analysed the occurrence and importance of each CSF in the categories, as shown in Table 10. The rate of occurrence represents how often a CSF was mentioned, while the rate of importance is the ratio of positive to negative annotations.

Table 9. Final CSF-list for modular value chain integration (o.i., 2022)

Label	Category	Critical Success Factor
Synergy	*Communication*	1. Effective communication
		2. Shared understanding in messaging
	Collaboration	3. Collaborative working environment
		4. Long term partnership
		5. Established collaboration structure
		6. Early involvement of key parties
	Information sharing	7. Early and effective use of information/communication technologies
		8. Frequent information/knowledge sharing
	Culture	9. Thrust among employees
		10. Morale and motivation
		11. Top management commitment
Competency	*Adequate experience*	12. Adequate technical and practical experience and knowledge
		13. Maturity of techniques through retrospective feedback
	Modular production principles	14. Early design freeze
		15. Defined design & technical specifications of product
		16. Scalability through standardization and product configuration
Organization	*Management*	17. Coordination between interfaces
		18. Link between project/design and product/production
		19. Early planning and scheduling
	Structure	20. Change in development process
		21. Effective alignment on responsibilities and expectations

1. CSF 12 – ADEQUATE TECHNICAL AND PRACTICAL EXPERIENCE AND KNOWLEDGE

Having "adequate technical and practical experience and knowledge" is crucial for the success of a modular construction project. The lack of experience among the team members can lead to a lack of understanding and a lack of collaboration between different parties. The interviews revealed that, in the case of Lister Buildings, the lack of experience among the team members was an obstacle in the industrialization and product development process. The team members were aware of the importance of adequate experience, but the lack of it resulted in a tendency to think quickly in traditional structures from the construction environment and less thinking in a combination of a product mindset. Furthermore, the interviews highlighted that the team members at Lister Buildings were understaffed to scale, which prevented them from scaling up within the given time. The start-up environment in the company also led to job gaps that needed to be filled until a specialist could be hired for the role.

> *"I think at Lister Buildings there's a lot of construction experience and little from the product environment. That doesn't make it easy to get into each other's mindset to understand that, also because construction is organized differently"* ***– Architect***

2. CSF 15 – DEFINED DESIGN & TECHNICAL SPECIFICATIONS OF PRODUCT

According to the insights from the interviews, it is clear that there is currently no standardized product at Lister Buildings. This presents a number of challenges for the different parties involved in the project, including the developers, architects, engineers, and manufacturers. Developers have no basic module information to work with, making it difficult to capture designs early in the project. Additionally, architects are still approaching assignments in a traditional way, creating new modules dimensions for each project rather than utilizing repetition in design and production. Engineers missing the lack of repetition makes it difficult for them to improve the product with new innovations as the previous models don't resemble with the next product. This difficulty extends to manufacturing, where it's hard to set up continuous assembly lines due to the unique features and alterations in the modules that make it difficult to establish a consistent workflow.

According to the interviews, there is a need for a standardized product (80%), with reasonable design freedom (20%) to work with fundamental starting points. This will enable a more efficient build process and allow for more repetition in projects. The philosophy for standardization is present, but there is not yet a clear understanding of what the product should be. There is a lack of standardization that results in extra work for everyone, including in the work preparation process.

> *"One of the biggest differences between construction vs manufacturing process, is that manufacturing process it has to be clear what the product is. That is where we have not been able until now to define the product. What is the module? What are the configurations of the buildings? The Lego bricks have to be determined first, and once you have determined that you can build the system and then build the special bricks around it. We are now mainly building special bricks, so it did not become a system. The system became too complex so the creation process also became too complex."* ***– System Engineer***

3. CSF 18 – LINK BETWEEN DESIGN AND PRODUCTION

This critical success factor is another addition to the existing CSF-list. "Link between Design and Production" has several insights and areas for improvement in terms of value chain management. One major issue that has been identified is the gap between the design side and the production side. This gap is caused by a lack of communication and collaboration between the two sides, resulting in a lack of understanding and knowledge of the design and production processes. This can lead to issues such as translation report errors, miscommunication between the different departments and "over-the-wall" problems that occurs when builders are left to interpret designs they weren't involved in creating (Wuni, Shen, & Osei-Kyei, 2022). This can result in "information islands," or disconnected bodies of information that need to be shared. These information islands can lead to schedule risks, such as a gap in design information between the designer and manufacturer, or inconsistency in logistics information (Li et al., 2017), resulting in significant delays in modular construction projects.

To improve this, it has been suggested that LM needs to be more involved in the design phase, to help bridge the gap and ensure that the design is feasible and manufacturable from the start. However, the department is facing shortcomings in personnel, especially in terms of work planners and people with product experience, which is also contributing to the gap.

To address this, it is important to have someone with both project and product knowledge, who is present from the beginning of the project and aware of the technical characteristics and performance of the module and runs with the whole project, which is important for translation. In addition, the role of LO, as the glue in that because they deal with integrating the design with everyone else has been identified as an important role in filling the gap between design and production.

> *"We discuss this weekly in the team: how to connect with the factory. How to incorporate the information that plays there into our design, but also vice versa, how our design lands well there.* ***– Architect***

It is also mentioned that the company is lacking a project management branch, which is crucial in ensuring that the design is translated correctly to production and that all the parties are working in coordination. The key is that the development of a standard product would help in fixing routine in design, which will lead to an early involvement of LM, which in turn will lead to a more efficient translation to production.

> *"I think that LM should have one product developer, who should make the module like the LEGO cubes we can manufacture and together with LO to see the development on building level. Then LO will be more about the total building "how could you standardize that" and LM at the module level. I think that would be an improvement to get to a standard module faster. LO now does both and I think you should pull that apart!"* ***– Manufacturer***

4. CSF 16 – SCALABILITY THROUGH STANDARDIZATION AND PRODUCT CONFIGURATION[2]

Standardization and product configuration are crucial for scalability in modular construction projects. However, the interviewees from Lister Buildings had differing opinions on the level of standardization that should be implemented. While the Lister Development (LD) emphasized the need for design freedom, other teams, such as the Lister Architecture (LA) and Lister Manufacturing (LM) recognized the importance of a standard product for scaling up the company. They see the ideal solution as a balance between having a manufacturable product that can handle exceptions while also being able to serve a large part of the market through a standardized variety of modules. The company is still in its early stages and as such, scaling up is difficult as they still have no standard product, and no specific focus on the kind of organization and flow in the factory, also they do everything 3D/2D/hybrid and complex/diverse projects. To achieve scalability, the company needs to focus on limiting the number of modules, separating standard and unique parts in their projects and implementing a separate production line for standard parts while focusing on unique process mapping.

[2] Product configuration, or the ability to customize modular components to meet the specific needs of a project, is *"putting together a product from well-defined building blocks (modules) according to a set of predefined rules and constraints"* (Sandberg et al., 2016).

5. CSF 21 – EFFECTIVE ALIGNMENT ON RESPONSINBILITIES AND EXPECTATIONS

In order to effectively align on responsibilities and expectations within the value chain management, it is important to clearly define and separate the responsibilities of each team. For example, LO works on the development of systems, while LM is responsible for producing the final product. LA designs a quality project that is in line with the product that LM produces. LD works towards ensuring the feasibility of the project and provides necessary resources. While each team has its own specific responsibilities, it is important for them to work closely together and have a clear understanding of each other's deliverables and responsibilities. This can be achieved by creating a clear organizational distinction, such as separating responsibilities based on project (building) or product (module) level, and having transparency in responsibilities. However, due to the startup environment, there may be some overlap in tasks and responsibilities, so it is crucial to have joint coordination to ensure the success of the project.

> *"It also has to do with going from start-up to scale-up to corporate, you have a very small cell of people working within that start-up and they all have more expertise in more aspects. There are gaps and you fill those by taking on other activities which are not necessarily your speciality. At some point, you grow so you can become more and more specialized by hiring those very people. Until you fill up everything and then you run successfully, more efficiently and more productively"* ***– System Engineer***

6. CSF 5 – ESTABLISHED COLLABORATION STRUCTURE

During the early phases of the project, there was a lack of an established work structure, which resulted in a disorganised approach to tackling the project. However, as the project progressed and external consultants were brought in, a more structured approach was implemented through scheduled appointments. Despite this improvement, there were still issues with the lack of prioritization for cooperation between different parties due to work pressure.

On a positive note, the importance of learning lessons from previous projects was recognized by the LA, LO, and LM teams, and regular meetings within teams were held to ensure that these lessons were shared and implemented in future projects. However, the structure was not as well-established between teams, and there were irregular meetings outside of teams.

> *"I think we should go to a system in which you clearly agree on things in advance. If an acquisition lands, which meets the following conditions, that we will have a standard routine of when we will speak to each other and when we expect certain things."* ***– Developer***

7. CSF 6 – EARLY INVOLVEMENT OF KEY PARTIES

The critical success factor of early involvement of key parties is essential for the successful integration of the value chain in a modular construction project. This includes the involvement of key parties such as LO and LM at an early stage in the project. It was noted during the interviews that the LO is not always optimally utilized by other parties due to the fast-paced nature of the business. Also the involvement of manufacturing was not always optimal, which led to unexpected changes in the design of modules and in the project, resulting in delays and cost overruns.

However, the early involvement of these key parties can lead to the strengthening of cooperation and collaboration. Additionally, involving parties such as Manufacturing and Engineering at an early stage for manufacturability and having them actively participate in the project can be seen as a logical solution and can easily initiate collaboration. Furthermore, it was noted that the LD and the LO can play a role in strengthening cooperation. Additionally, LA should be involved at an early stage to ensure that all parties are aware of the project's goals and requirements

> *"Actually, you should get someone from production involved much earlier and be aware of what's going on. Because we've divided it so much, some people are being called in too late."*
> ***– System Engineer***

8. CSF 17 – COORDINATION BETWEEN INTERFACES

The critical success factor of coordination between interfaces in value chain management is a crucial aspect of achieving successful modular construction projects. The insights from the interviews suggest that there is a need for improved contact between the different teams involved, particularly between the architects and manufacturers. LO can play a key role in connecting the different teams, while the LD can provide support in coordinating their efforts. The developer is classically seen as the project leader, however, when it comes to the product, LA or LO teams may take on a larger role as the product leader. LA is also seen as the most important intermediary in coordinating the different parties. Effective leadership and transparent planning are essential in ensuring successful collaboration between all teams involved.

> *"The whole development process is the developer taking the lead. But if you ultimately approach to systems thinking then there would be a much larger role for the systems architect or LO."* ***– Developer***

Conclusion

The results of the interviews with participants in a modular construction project revealed several critical success factors for the integration of the value chain. A brief analysis of the CSFs indicates that a lack of adequate technical and practical experience and knowledge among team members can hinder understanding and collaboration and lead to traditional structures instead of an agile and BIM-based approach. The lack of standardization in product design was also a challenge, leading to extra work, inefficiencies and restrictions in scaling the business. The gap between design and production was identified as another area for improvement, with the need for someone with both project and product knowledge and increased involvement of production in the design phase.

Source: Lister

9

Findings

9. Findings

This chapter will further elaborate on the data retrieved from the case study and literature review. The results are analysed based on the top eight of the CSF-list, the data from the coordination exercise and the data gathered from the current and future production system profiles. The discrepancies and linkages between these aspects are discussed and substantiated in relation to one another and to the literature. The analysis is split into the three different labels: competence, organization and synergy.

9.1 Competency

Having “adequate technical and practical experience and knowledge" is crucial for the success of a modular construction project due to the two sectors colliding: construction and manufacturing. It is difficult in many ways already difficult to merge two worlds, so having experience and developing skills to be able to manoeuvre in both project and product ways will come in handy. The interviews revealed that, in the case of Lister Buildings, the lack of experience among the team members was an obstacle in the industrialization and product development process. the interviews highlighted that the team members at Lister Buildings were understaffed, which prevented them from scaling up within the given time. Individually there is a difference to be noticed between the management positions and the team members. Four out of five from the management board have defined Lister Buildings' profile to more design approach in comparison to their internal team. This difference could be explained by the difference in operating levels. During managerial meetings, additional information about the company is discussed which is not always shared within the teams. Therefore the managerial team has more knowledge and could act more critically in comparison to the other team members' perceived experiences.

Additionally, the data suggests that there is a company-wide commitment to improving the production processes, but currently, there are differences in the departments' views on design variety and standardization to develop **“defined design & technical specifications of the product”.** While LD emphasized the need for design freedom, other teams, such as the LA and LM recognized the importance of a standard product for scaling up the company. This tension is likely due to conflicting priorities and goals. First, the LD team is focused on adding projects to the pipeline and wants the freedom to create unique and customized solutions to stay competitive with the traditional market and being attractive to the clients, while LA and LM teams see the benefits of having a standardized product that can be easily manufactured and scaled to meet the needs of a large portion of the market. This misalignment leads to a setback in the progress of modular projects towards a more efficient and standardized approach. Instead of using a set of pre-defined modules, each project is designed with custom modules once the floor plan and mass study is completed. This approach negates the benefits of modular construction and is inefficient. Secondly, the departments of LO and LM could have more employees with previous work experience in product-based environments, making them more critical in judging the current profile of Lister Buildings.

Additionally, the results of the Production System Profiles support this analysis as they show that all departments aim to shift towards a more product-oriented approach in the of “**Design Type”, “Production Configuration”**, **“Production Rate”,** and **"Delivery Time"** characteristics. This shift is aimed at improving the production processes for increased efficiency and profitability. This may involve making trade-offs between customization and scalability, as well as balancing between product quality and delivery times. This is displayed in the profiles discrepancies around **“Design variety”**. It shows clear conflict with the different departments as LD, LA and LO’s data argues towards a balance between standardization but still offering enough design freedom to cater to the client's need, whilst LM data suggests that the design variety will take a more limiting range. The standardization of products is also important for other reasons as well. It allows for clarity during the acquisition process (cost price) for LD, allows LA to have clarity on what they can use to configure the project and tackle unique parts, enables LM to have repetition during a more efficient build process, and allows LO to have a fixed product to drill down for innovation. To solve this problem, Lister Buildings could invest in research and development for the standardization of product by defining the set of modules to be configured in a range of residential-concepts.

By standardizing the design and production of modular components, companies can streamline their manufacturing processes, resulting in **“scaling the business through standardization and product configuration**”. Modular construction companies can increase their appeal to a wider range of customers, leading to an increase in sales and revenue. Being able to quickly and easily customize modular components can reduce lead times and improve project delivery and increase its competitiveness in the market (Wuni & Shen, 2019).

Overall, the combination of standardization and product configuration allows modular construction companies to increase efficiency, volumes, reduce costs leading to economies of scale (Gann, 1996) and better meeting the needs of their customers, all of which are important factors in achieving scalability in the industry.

9.2 Organization

One of the most important factors in successfully aligning and integrating cross-functional teams in a modular construction environment is to have **a link between the design and production teams**. It's important to link the design and construction to avoid the "over-the-wall" problem that occurs when builders are left to interpret designs they weren't involved in creating. This can result in "information islands" or disconnected bodies of information that need to be shared (Wuni, Shen, & Osei-Kyei, 2022). These information islands can lead to risks such as a gap in design information between the designer and manufacturer. Therefore, it is important to ensure consistency in information sharing within the integrated value chain to facilitate this smooth project delivery and coordinate the process between the two environments (Wuni, Shen, & Saka, 2022). It is essential to have someone with both project and product knowledge involved in the project from the start. This person should be knowledgeable about the technical features and performance of the modules and be responsible for overseeing the entire project. This is critical for ensuring effective communication and translation of the project goals and requirements. Having the same person on multiple teams can facilitate information transfer.

The data suggests that to achieve effective integration, there needs to be an **“effective alignment of responsibilities and expectations”** and **“coordination between interfaces”**. The results of the **Coordination Exercise** showed that there is a lack of clarity about who is responsible for each phase of the project and that different departments have different perceptions of who the primary coordinator should be. This lack of clarity was also highlighted in the interviews, where it was reported that in the start-up environment, there was a general vagueness about the division of responsibilities, leading to confusion about which tasks belonged to which role. This further exacerbated the problem of confusion regarding the responsibilities of each party involved.

9.3 Synergy

From the data, it became clear that to increase productivity and efficiency, prior to a project coming in, a discussion between the departments is necessary to systematically go through the actions that are expected from one another. Having “**clear alignment between key players”** on expectations and having a systematic approach to a modular construction project can lead to the effective achievement of planned objectives, according to Choi (2014). When all departments understand and agree on the goals, objectives, and benefits of using modular construction, they are more likely to work collaboratively and coordinate effectively, reducing conflicts and delays in project delivery. Aligning responsibilities and expectations can therefore be a key driver for successful collaboration among the key players in modular projects. The data from the case study indicates that the low deltas in "**Focus Perspective**" of LD and LA suggest that their current approach aligns with their desired future operating profile, which they experience as a balance between themselves and LM. However, LM has a different view on this, indicating that they do not experience their reality, which displays a discrepancy in perceptions of collaboration between the design and production parties, presenting a case of misalignment within the company.

"Collaborative working environment" The close ties between departments in some phases suggest a shared responsibility for the success of the project, but it remains to be seen if all activities are suitable for shared responsibility. Despite these challenges, the importance of learning from previous projects is emphasized by LA, LO, and LM, and there is a management-level structure in place, although there may be less structure between teams. The close communication between departments and the ability to quickly involve other departments is seen as a positive aspect of the working environment. However, there may be some challenges such as a large distance between departments, a hybrid work environment, and cultural differences that need to be taken into consideration.

The data from the case study indicates the importance of "**early involvement of key players"** in ensuring the success of vertical integration in modular construction. This involves involving parties such as LO and LM in the project from the beginning, which can lead to strengthened cooperation and collaboration. Both Manufacturing and System Development understand the importance of their involvement and are willing to participate. However, there is currently no established structure in place for collaboration between the departments, which can lead to a haphazard approach to tackling the project. The high workloads of the departments can also result in a lack of prioritization given to collaboration.

9.4 Improvements

During the interviews, there were suggestions made by the employees on how to tackle certain issues within the company to foster and improve integration. Some improvements were mentioned frequently so that certain CSFs could be formed. Coming from experienced employees and the rate of occurrence that had been mentioned throughout the interview, these CSFs might pose as solutions to similar companies or similar industries. The entire list is to be found in Appendix H.

CSF 20 – CHANGE IN DEVELOPMENT PROCESS

Another addition formed from multiple interviewee statements is the change in the development process of the company. It is currently seen as too traditional and not optimal for modular construction in certain areas. The expert workshop that was held was seen as useful, but it was noted that it was a bit superficial at the front end of the process. It was suggested that another session should be held to delve deeper into the Technical Design (TO) phase and during the UO phase.

In terms of the development process, modular construction projects can also differ from traditional projects. Because the modules are fabricated off-site, there is an increased emphasis *on planning and design/configure*, to ensure that the modules fit together properly and that all the required building systems are integrated. One key insight is that if the product is fully developed and understood, with all the necessary technology incorporated, then it is possible to be able to skip the VO and move directly from the SO to DO phase, thus shortening the development phase. This is because the acquisition phase is out of the company's control, but the development phase is not. Another suggestion was that with technology already incorporated into the modules, there may not be a need for a TO phase. The suggestion was made to create project teams within Lister for maximum collaboration, and to classify the process differently in order to shorten it and possibly even skip the VO phase. This requires more coordination and communication among the different stakeholders, as they work together to develop a modular building that meets the desired specifications and performance requirements.

The role of LM was also mentioned, as they are often seen as only responsible for the production of the product. However, it was pointed out that they should be involved earlier in the process to give input on what can be made. Overall, the process of approaching a project was seen as being too traditional and there is a need for a change to make it more efficient.

CSF 2 – SHARED UNDERSTANDING IN MESSAGING

One of the critical success factors that have been newly identified during the analysis of the interviews is a shared understanding of messaging, among all stakeholders involved in the modular construction project. According to Jassawalla and Sashittal (1998), mutual understanding and transparent interaction within cross-functional collaboration are crucial for effective communication. In other words, effective cross-functional collaboration requires communicating the understanding of different perspectives and the ability to generate new ideas through teamwork. In a work setting, when employees from different departments or teams come together to work on a project and are able to find common ground and establish a shared understanding, it can lead to more productive and successful meeting.

The insights gathered from the participants indicate that there are currently some challenges in achieving this factor. One of the main issues is the lack of a clear and consistent understanding of key terms and definitions related to the project environment and used in the modular construction context. These definitions are often chosen for convenience among internal and external parties but do not necessarily lead to optimal results in the modular construction process. Additionally, participants noted that the concept or terminology of "standardizing" is relative, as it can refer to both the project as a whole and an individual product. This lack of a common understanding of key terms and definitions can lead to confusion and miscommunication among stakeholders, resulting in inefficiencies and delays in the project. To address this, it is important for all stakeholders to work together to establish clear and consistent definitions that align with the modular construction process and to ensure mutual understanding and common ground among all parties involved.

CSF 13 – MATURING OF TECHNIQUES THROUGH RETROSPECTIVE FEEDBACK

The maturity of techniques used in modular construction projects, such as building information modelling (BIM) technology, is important because it can expedite the learning curve and improve the organization's understanding and efficiency in the processes involved (Nawi et al., 2012). This can lead to better cross-functional collaboration and a willingness to change among team members (Holland et al., 2000), which is essential for the success of modular construction projects. The detailed design phase, in particular, requires a high level of technical knowledge and skills to transform construction drawings into assembly drawings with accurate dimensions and connection methods (L. Li et al., 2018).

Systematic performance measuring and re-use of experiences refer to the practice of collecting and analyzing data on the performance of a modular construction project in order to identify areas for improvement and to inform future projects. This includes gathering retrospective feedback from team members and stakeholders and analyzing data on cost, schedule, and quality to increase the maturity of techniques used in modular construction projects, leading to better coordination and collaboration between stakeholders and ultimately, more successful projects (Kamar et al., 2010; Wuni, Shen, & Osei-Kyei, 2022; Wuni & Shen, 2019).

However, in practice, the participants in the case study mentioned that they were not able to gather such feedback because they did not have the time. They shared that they needed more time to learn from their mistakes and improve the next project. The participants also noted that their projects were overlapping, which made it difficult to take the necessary lessons learned from one project and apply them to the next. Despite this, they expressed confidence in their ability to grow as a company by actively incorporating feedback retrospectively and understanding the consequences of modular building. LA plays an important role as an intermediary for common understanding within the company. Additionally, the regular reporting between LO and LM is seen as a step towards incorporating feedback. Also, it is also noted that the LD could improve productivity if the basic information, such as design principles and realization principles, could be shared by LM.

> *"We have recently begun "Lessons Learned" from a variety of projects. So that we may apply these lessons and challenges to our system development and grow on them."*
> ***– System Engineer***

Source: Lister

10

Discussion

10. Discussion

The discussion chapter provides an opportunity to reflect on the findings of the study and draw meaningful conclusions about the research question. This chapter will discuss the practical and theoretical implications of the results and limitations of the research.

10.1 Practical implications

The need for improved coordination and communication between different teams in the value chain, including architects, manufacturers, and project managers, is a key implication of the integration of the value chain in modular construction projects. This is because communication is required in order to achieve integration, which in turn can help to ensure that all parties are working towards a common goal and that everyone is aware of their respective responsibilities.

Merging the project and product approaches in the construction industry can have a significant impact and bring about a number of implications. By combining these two opposite disciplines, the construction industry has the potential to bring about significant benefits and improvements in efficiency, innovation, sustainability, and customer satisfaction if executed correctly.

From this research, one main implication can be noted and that is the impact the opposite disciplines have on this industry. Merging two opposite disciplines, project and product approaches in the construction industry can lead to a number of negative implications if not executed correctly. The main problem is the risk of miscommunication and misalignment between different stakeholders due to the different perceptions and goals that each discipline holds. This can result in inefficiencies and an inability to scale the industry.

Without clear lines of communication and understanding between the project and product approaches, there is a risk of misunderstandings, duplication of efforts, and conflicting priorities. This can lead to delays, cost overruns, and a lack of overall cohesion in the industry. Additionally, the different methodologies and processes used in the project and product backgrounds can create a barrier to integration, making it difficult to align expectations and responsibilities. This can result in a lack of clarity and direction, leading to further inefficiencies and issues.

It is important to address these challenges in order to effectively merge the project and product approaches and reap the benefits of integration. This requires a commitment to collaboration, clear communication, and alignment of goals and expectations across the industry.

10.2 Theoretical implications

The research focuses on the integration of modular construction value chains, taking into account insights from various disciplines in the construction and manufacturing industries. The study presents a conceptual framework to enable value chain integration and then examines the context in what way this integration should occur within the modular construction industry. The specific characteristics of modular construction products are then analyzed, and finally, the research investigates how the integration of value chains can help to improve the efficiency and productivity of the modular construction sector, moving it away from its current underperformance.

Conceptual framework

The integration of modular construction value chains has been gaining traction, focusing on the shift towards off-site production and manufacturing approaches and how it can lead to improved outcomes in terms of productivity, efficiency and overall project performance. This research aimed to examine, find and solve the link between value chain integration and the impact of having a suitable production system. This was executed by linking two concepts: a CSFs list to enable integration of modular construction value chains and defining the range of different production systems. The use of the CSFs helped this research to gain a grip on what was considered impactful for integration as they were consolidated by experts in this field. However, the CSF from the papers could have misalignments in context politically, geographically, economically and regulatory. Therefore, the list was tested by using the CSF as a coding method during an extensive single case study. Using this list to structure the unstructured retrieved transcribed data of the interviews helped to organize this research. Through the rate of occurrence and ratio of importance, the CSF could be shaped into a list that filtered out the factors that did not align or found relevance in this context and the ones that did. This method was found very effective in using years of experts' experiences by using their pre-defined substantiated CSFs, and applying it to a particular context.

However, it is worth noting that there were limitations to this method that may have contributed to some inaccuracies. As this research involved human participants, the risk of inaccuracies is always present. The coding of the transcribed interviews was based on the researcher's own knowledge, expertise, and experience, which could have influenced the results. Additionally, the lack of linking keywords to the critical success factors (CSFs) made it more difficult to substantiate the labelling of certain quotes with certain CSFs.

Another limitation of using the CSF methodology is that it can be subjective and dependent on the researcher's own biases and perspectives. As the researcher is the one who codes the transcribed interviews, their own experiences, beliefs, and interpretations can influence the results. This can result in a lack of objectivity and consistency in the coding process, which could potentially lead to inaccuracies in the findings.

Another limitation of using the CSF methodology is that it may not fully capture the complexity and nuances of the real-world challenges faced in integrating modular construction value chains. The CSFs were consolidated from prior research and expert opinions, but they may not fully reflect the unique context and conditions of each individual project. This could lead to oversimplifications or oversights in the analysis and findings of this research.

Through derived from the results are overlapping outcomes with the production system. By developing and shaping the CSF-list through a substantial literature review and a single case study, the results showed that this integration can lead to a more streamlined and efficient construction process, with clear positive results in aligning the production system to the defined product which influences the degree of integration. Overall, this research highlights the potential benefits of integrating modular construction value chains and suggests that this approach is well-suited to meet the demands of the modern construction industry.

Profit margin

Another interesting implication of the research is the significant discrepancy in the “Profit Margin” characteristic in the production system profile exercise. The results suggest that the modular construction company is considering ways to improve efficiency and cost-effectiveness in their product design and production processes in order to increase the profit margin per module, while still meeting the unique needs of clients. However, this is, in manufacturing literature, linked to project environments, as unique/one-of-a-kind products are produced on low volume, with more specialities and labour skills indicating a larger profit to be made per product, whilst in the product environment the opposite is the case, with a lower-profit per margin. This indicates a discrepancy in applying literature from the product environment to the manufacturing industry.

10.3 Limitations

The research presented in this thesis had several limitations that should be taken into consideration when interpreting the results. Firstly, the scope of the research was limited to the departments of development, architecture, manufacturing, and systems engineering, and did not take into account the perspectives of other departments or stakeholders involved in modular construction projects. Secondly, the research did not consider the financial implications of integrating the value chain, which is an important aspect of the modular construction industry. Thirdly, the research did not include the influence of external regulatory bodies, which can have a significant impact on the success of modular construction projects.

Another limitation of the research is that it was limited to the development phase of the project process, and did not consider other important phases such as acquisition, on-site construction, and operations. Furthermore, the research was based on only one case study, which means that more case studies are needed to validate the findings and generalize them to the larger modular construction industry.

In terms of the research methodology, there were limitations related to the accuracy of the triangulation of the interviews as the LO only had two participants. Also, due to limited suitable candidates, it was inevitable to have a participant of the company participating in the interview who was aware of my research goals, therefore making their statements biased and less valuable to the research. Furthermore, there were potential issues related to the relative understanding and interpretation of terms used in the interviews, as the participants may have come from different backgrounds and had different definitions for certain terms. Additionally, the characteristics of the production systems were not always clear, and some systems were too similar, which caused confusion in the analysis.

Finally, the research could have benefited from a better definition of terms, particularly when asking participants to rank the importance and responsibility of different aspects of the value chain integration. The interpretation of these terms may have been different among participants, which could have led to inaccurate results.

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Source: Lister

11

Recommendations

11. Recommendations

The Recommendations chapter provides an overview of the key findings and conclusions drawn from the previous chapters of this research paper and offers practical recommendations for industry stakeholders and future research. The first subchapter provides specific recommendations for Lister Buildings, based on the findings of this research paper. The second subchapter provides more general recommendations for the broader modular construction industry and other industries that may benefit from the insights gained in this study. The third subchapter provides recommendations for future research, identifying areas where further investigation is needed to deepen our understanding of the topics explored in this research paper.

11.1 For Lister Buildings

One way to bring modular construction one step closer to industrialization, meaning high efficiency and productivity in the production and construction process, is to decrease the interfaces by integrating the value chain. This organizational structure can also be seen in product environments, which have been established as the trajectory for the future of modular construction to resemble a mix between project and product disciplines. To achieve a more product-based environment while integrating the value chain the following points are necessary to address.

- **Defined design & technical specifications of the product** The absence of a standard product leads to inefficiencies in design and production, causing a lack of early involvement of LM and inefficient translation to production. One solution to address the lack of defined design and technical specifications of the product is to establish clear and standardized specifications. This can be done by involving the manufacturing team (LM) early in the design process and ensuring a smooth translation of the design into production, and by setting up a product development team focussing on the module level and LO evaluating and improving on project level. This will improve efficiency and help avoid inefficiencies in both design and production.
- **Find the balance between design freedom and a standard product for scalability**. To achieve scalability, the company needs to focus on standardizing their design process with predefined modules, separating standard and unique parts in their projects and implementing a separate production line for standard parts while focusing on unique process mapping.
- **Regain clear alignments about expectations and responsibilities.** There are misalignments about coordination responsibilities between phases in their current and future decision-weight are of importance. Even though this might be an effect of the start-up environment by filling in job roles, this should be frequently discussed between the parties to regain its alignment.
- **Link between design and production** One major issue that has been identified is the gap between the design side and the production side. This gap is caused by a lack of communication and collaboration between the two disciplines, resulting in a lack of understanding and knowledge of the design and production processes. To resolve this, one can explore the possibilities of an internal member being chosen to fit the criteria of being the link, with its responsibilities. A system engineer (LO) might be the right fit for bridging the gap as they have a broad understanding of the entire system and can ensure that all components are designed and integrated to work together efficiently. They can also help to identify potential issues that may arise during the production phase and work with the design team to resolve these issues before they become problems in the production process. Otherwise, setting-up a project management department would suffice to coordinate the two opposite disciplines.
- **Coordination between interfaces in value chain management.** Improved coordination between different teams in the value chain is crucial for successful modular construction projects. The interviews suggest a need for better communication between architects and manufacturers, as well as strong leadership to manage collaborations and ensure involvement from all parties. The developer is seen as the project leader initially, but the role of the product leader, such as the LA or LO, becomes more important as the project progresses. Good chairmanship is essential to manage effective collaborations between the two disciplines.

Moving to the MTO or ATO production systems. Due to their overlapping objectives with product characteristics, these production systems should be able to align with their future production profile. The MTO and ATO systems are designed to cater to individual customer requirements and allow for greater flexibility in the production process, due to their pre-defined nature. This could help to bridge the gap between design and production and ensure that the design is feasible and manufacturable from the start. In order to implement this production system effectively, it is important to ensure that clear and consistent definitions and key terms related to the project environment and the modular construction process are established. This will help to ensure mutual understanding and common ground among the different disciplines involved. Additionally, the MTO and ATO systems could improve the integration and coordination of the various players within the value chain of a modular construction project, as they allow for increased collaboration and communication between different teams, due to creating routine and consistent processes through standardization. Inform Appendix B, for the different characteristics.

11.2 For modular construction and similar industries

Another outcome of this research is the completion of the CSF-list. Through a thorough single case study new factors were discovered and added to the existing list. Also by using the preliminary list as a coding tool the list was (in)validated. All these factors were compiled and are to be found in Appendix G. Some of the key areas that the CSF-list can help address include aligning responsibilities and expectations among team members, improving communication and collaboration, developing a standard product, addressing the gap in personnel, fostering a collaborative working environment, and establishing clear and consistent definitions and terms – all related to enabling improved integration and collaboration between the value chain members.

By using the CSF-list as a starting point, modular construction and similar industries can ensure that they are taking the necessary actions to integrate their value chain effectively, while balancing profitable production systems with productivity and efficiency. The CSF-list can also serve as a tool for continuous improvement, as industries can use it to assess their progress and make changes to their processes as needed. This will help shape the list as well for different industries with similar profiles of project and product characteristics. Do check the "Discussion" chapter for the limitations and implications to avoid any repeating shortcomings.

There are a few recommendations for the modular construction industry and other similar industries seeking to integrate their value chain for productivity and efficiency while balancing profitable production systems. Companies with a project-based and product-based approach are able to follow the step-by-step approach of creating an environment where value chain integration flourishes.

- **Foster a culture of togetherness with team- and intrinsic motivation**: Ensure a real commitment and understanding of the specific method used by communicating a strong and clear vision for the project and aligning the different team with it.
- **Develop a shared understanding of messaging and communication:** This involves ensuring that everyone involved in the project has a clear understanding of the communication channels, language and messaging that are being used and that these are being used effectively avoid misunderstandings, to keep everyone informed and on track.
- **Align responsibilities and expectations among team members**: Ensure that all team members understand their roles and responsibilities, and what is expected of them.
- **Foster a collaborative working environment**: encouraging regular communication and teamwork across different departments and stakeholders. This includes coordinating efforts between the different teams involved, and having effective leadership and transparent planning.
- **Bridge the gap between design and production**: This means addressing the disconnect between the design and production sides of the value chain, by improving communication and collaboration between these two disciplines. This includes involving the manufacturing team in the design phase, and having someone with both project and product knowledge present from the beginning of the project.
- **Define the product in design and technical specifications:** Develop a standard product that can help fix routine in design, which will lead to early involvement of production teams and more efficient

translation to production. This means specifying the design and technical requirements for the product so that everyone involved in the project has a clear understanding of what is required.

- **Find the suitable production system for the product characteristics**: Determine the most appropriate production system for the product based on its characteristics and requirements.
- Standardize and simplify processes for scalability: Streamline processes, simplify procedures, and standardize approaches to make the development process scalable, efficient, and effective.
- **Improve feedback management**: Provide more time to learn from mistakes and improve future projects, and foster trust among employees by encouraging long-term collaboration, repetition, and the ability to see improvements.

11.3 For future research

This chapter aims to provide a roadmap for future studies that can build on the findings and contributions of the current research. It will provide directions and identify areas that require further investigation to address gaps in the literature. It will also outline opportunities for new research and highlight the potential for future studies to contribute to the advancement of the field of exploring the potential of modular construction to enhance productivity, efficiency, and industrialization in the construction industry.

First, it is recommended to research one of the challenges in the modular construction industry: standardizing the product while still allowing for design freedom for the client. Future research could investigate the best ways to standardize the product, while still allowing for design freedom, and explore the trade-offs between standardization and customization in modular construction projects. This research could include case studies of similar industries or surveys to understand the best practices for balancing standardization and customization in the modular construction industry. It is of deep interest to the industry to have guidelines on which the range of modules and the possible configurations would be optimal for modular construction to foster standardization and customization.

Another research could dive into the different production systems. It is important to note that while moving to an MTO or ATO production system has the potential to improve the integration of the value chain, it may also present some challenges such as increased production lead time, higher production costs, and the need for more advanced production planning and control systems. Further research is needed to better understand the trade-offs and benefits of these production systems in the context of modular construction, as these definitions are derived from the manufacturing industries.

Last, but not least, while this study provides valuable on the integration of modular construction value chains, it is limited to a single case study. To further strengthen the validity of these findings, it would be beneficial to repeat this research format and methodology with other companies that have integrated value chains. This would allow for the validation or refutation of conclusions made in this study, as well as the confirmation of the applicability of the CSF list and its relationship with production systems. Additionally, conducting similar research in different industry sectors would increase the generalizability of the results, providing a more comprehensive understanding of the benefits and challenges of value chain integration across various industries.


Source: Lister

12

Conclusion

12. Conclusion

This study aimed to improve the efficiency and productivity of the modular construction process by providing practical recommendations for better collaboration and integration between developers, architects, and manufacturers in a vertically-integrated value chain. In order to achieve this, it was important to gain a deeper understanding of different production systems and their impact on cross-functional relationships. The research aimed to examine the feasibility of integrating the value chain in modular construction projects and to identify the challenges and success factors for its implementation in practice. The results of the study will be presented in the conclusion, which will provide insights to answer the main question:

"How do project- and product-based disciplines within the residential modular construction industry achieve effective vertical value chain integration during the development phase?"

In order to achieve a logical answer to the main research question, sub-research questions are formulated to provide a step-wise approach to answering the main research question. The following sub-research answers are:

1. What is (residential) **modular construction**, and how does its value chain work?

Residential modular construction is a building method in which individual standardized elements of a building are manufactured in a controlled environment into 3D modules and then transported to the construction site for assembly or, in 2D where the elements are brought to the construction site and assembled on site. This method has several advantages, such as lower production costs, reduced construction time, improved quality control, and increased safety. However, it also has challenges, including high start-up costs, coordination difficulties, limited customization options due to an early design freeze, and logistical issues such as transportation restrictions and costs. The value chain for residential modular development typically involves several key players, including but not limited to developers, architects, system engineers and manufacturers.

In comparison to the traditional construction value chain, the modular construction value chain has several key differences. Firstly, the presence of a manufacturing party to produce the modular components for the building. This means that the roles and responsibilities of traditional players such as architects, developers, and contractors are altered, with architects working with standardized elements that limit their design freedom, and developers taking on a different position as they may come directly to the manufacturer to produce modular homes.

2. Which **production system** will fit the modular production strategy?

The degree of repetition in the product was hypothetically expected to have an impact on the production process and the collaboration and cohesive integration of the value chain including designers, engineers, and manufacturers. When the product and production process is repetitive and standardized, it can lead to improved collaboration and integration among the different members of the value chain, as everyone is working from the same specifications and processes. This results in greater standardization and simplification of the design, engineering, and manufacturing processes. However, when the production process requires more customization and variation, it can pose challenges for designers, engineers, and manufacturers to work effectively together, as each stage of the process may have different requirements and constraints. Therefore it was of the essence to gain knowledge of the different production processes with the variables categorically divided between the two extremes: the project or product approach.

The future of modular production strategy depends on various factors such as the organization's goals, resources, and market demand. Some organizations may prefer a project-based approach, where they prioritize delivering unique projects that are tailored to the specific needs of the client. On the other hand, organizations that place a greater emphasis on efficiency, cost-effectiveness, and profitability may prefer a product-based approach, which typically involves a long-term internal team structure, strong external relationships with suppliers and partners, and a focus on production rate, design type, and product configuration.

The standardization of products is also important for other parties. It allows for clarity during the acquisition process (cost price) for the developers, allows architects to have clarity on what they can use to configure the project and tackle unique parts, enables the manufacturing party to have repetition during a more efficient build process, and allows system engineering to have a fixed product to innovation.

In this research, through a thorough single case study of a modular construction company with an integrated value chain, the future of their production strategy will shift towards a more product approach, while embedding some design freedom in the form of several pre-defined modules to be configured to a range of homes. This instils the client with their perception of freedom in their design process with LD, while LA is able to design in a more systemic way which gives makes them go quicker through the design process and gives them more time to focus on the unique features of the building. With the majority of the building being pre-defined and familiar to them to build, will create more growing space for LM as they will be able to create a routine for the engineers when creating the UO design, for the assemblers during the assembly phase whilst scaling their assembly lines to producing higher volumes in a more continuous way through lean strategy. This production system would resemble make-to-order to assemble-to-order with the balance between the two to be discussed and compromised by the design and production team.

3. Which **critical factors** steer towards successful organizational integration within a modular construction value chain?

The list of the most effective factors is displayed below. Adequate technical and practical experience and knowledge of modular construction have been revealed as the most important factor to enable the successful integration of the value chain. Furthermore, other important factors are defining the design and technical specifications of the product, creating a link between the design and production team, use of product configuration with the previously defined products, having clear alignment between all parties on responsibilities and expectations of one another, establishing a collaboration structure to develop a predefine approach on project development, early involvement of production team and having clarity of the coordination between the interfaces.

Also, based on the interview data, it is clear that effective communication, shared understanding in messaging, and a collaborative working environment are catalysts for the factors mentioned above to successful integration and coordination among the various players within the value chain. Additionally, a supportive organizational culture with trust among employees, morale and motivation, and top management support is the foundation for all factors to thrive.

1. CSF 12 – Adequate technical and practical experience and knowledge
2. CSF 15 – Defined design & technical specifications of product
3. CSF 18 – Link between project/design and product/production
4. CSF 16 – Scalability through standardization and product configuration
5. CSF 21 – Effective alignment on responsibilities and expectations
6. CSF 5 – Established collaboration structure
7. CSF 6 – Early involvement of key parties
8. CSF 17 – Coordination between interfaces

"How do project- and product-based disciplines within the residential modular construction industry achieve effective vertical value chain integration during the development phase?"

The modular construction industry, like many other industries, faces challenges when it comes to integrating the value chain in order to achieve productivity and efficiency while balancing profitability. The case study of Lister Buildings, a modular construction company, highlighted several CSFs and areas for improvement that are relevant to the industry as a whole. However, the most profound statement from this report is that the modular construction industry is currently in an identity crisis, as the industry tries to merge two opposite disciplines: project and product.

Synergy

One of the key benefits of modular construction is that it allows for the pre-fabrication of the modules in a controlled factory setting, which can lead to higher quality and greater efficiency compared to traditional on-site construction methods. **"Establishing a clear and structured collaboration structure"** between departments is essential for the successful integration and coordination of the various players in a modular construction project. This includes **"early involvement of key parties"** such as the system engineer and the manufacturer at an early stage of the project, **"aligning responsibilities and expectations**", and having a systematic approach to the project. Learning from previous projects and regularly holding meetings within teams to share lessons and best practices can also contribute to a collaborative working environment.

However, there may be challenges such as physical distance between offices, cultural differences, and high workloads that need to be taken into consideration. To address these challenges, companies can consider implementing technology tools and platforms to facilitate communication and collaboration, providing training and education to employees to enhance cross-functional understanding and appreciation, and setting up clear protocols and procedures for coordination and cooperation. Additionally, it is essential to have a supportive and collaborative company culture with trust among employees, morale and motivation, and leadership that encourages and facilitates cooperation and collaboration across different departments and locations for all factors to thrive.

Competency

The findings of the study suggest that **"adequate experience in the modular construction industry"** is critical to be able to foster a fitting standardized, product-oriented approach while also having project-oriented approach to balance out the standardization with a level of customization. This balanced dynamic of approaches would provide the necessary design flexibility to meet the needs of clients, enhance design consistency, and efficient translation to production, which enables a more efficient and streamlined production process. Defining a modular design system with configurable designs is considered essential as an initial focus, as it allows for repetition and consistency, which in turn accelerates the acquisition of skills and knowledge. This can then be leveraged to enables the ability to expand and diversify into other designs more quickly.

A focus on modular design systems with configurable elements, design flexibility, and efficient and streamlined production processes - overlap with the characteristics of make-to-order (MTO) and assemble-to-order (ATO) production systems. Make-to-order production involves producing customized products based on specific customer orders. The products are typically not produced until an order is received, which means that the production process is driven by demand. In this type of production, the design and technical specifications of the product are well-defined in advance, and the production process is designed to be flexible enough to accommodate changes to the product based on customer needs. Assemble-to-order production, on the other hand, involves producing standard or modular components that can be assembled into customized products based on specific customer orders. The modular design approach allows for a degree of standardization and configurability, which can result in more efficient and streamlined production processes.

These characteristics also overlap with the top ranking CSFs **“defined design & technical specifications of the product”** and **“scalability through standardization and product configuration**” which are also showed to be essential in enabling smoother integration between the two disciplines.

<u>Organization</u>

Coordination is also deemed a critical value chain management tool to foster and protect the level of integration between cross-functional departments. However, the analysis showed that there were discrepancies in assigning a project carrier and breakdowns in communication between the design and manufacturing teams, which arose due to the merging of two different disciplines within the same industry. As decision-making authority shifts from the developer/designer to a combination of developer/designer/manufacturer, it becomes necessary to involve an individual who possesses both project and product knowledge right from the beginning of the project. This individual would be facilitating effective communication and interpretation of project goals and requirements. This could be in a form of a system engineer and manufacturer or the a project manager.

To address the issue of misalignment in project coordination, responsibilities and expectations, it is crucial to establish unambiguous guidelines and expectations for each phase of the project. This can be accomplished by creating a comprehensive project plan that clearly defines the roles and responsibilities of each team member and identifies the primary coordinator for each phase. It is equally important to ensure that all stakeholders have a clear understanding of their own roles and responsibilities and communicate effectively to prevent any misunderstandings or confusion. To facilitate this, it may be helpful to create a clear organizational distinction between responsibilities based on project (building) or product (module) level and ensure transparency in responsibilities.

The effectiveness of the proposed solutions is supported by the strong prioritization of certain critical success factors (CSFs), namely **"early involvement of key parties", "continuous effective alignment on responsibilities and expectations,"** and **"emphasizing the importance of a link between project/design and product/production"** to facilitate value chain integration.

In summary, it is of importance to initially create synergy between the two opposite disciplines to be able to create clear communication, collaboration, information sharing and culture in a project, which can be achieved in multiple ways. When that is in place, finding the balance between design and production principles between the competencies where both experiences can flourish. And lastly, but certainly as important, set up the appropriate management to foster clear coordination and alignment within the teams to help support the differences in disciplines throughout the phases of the process.

".ز خود برتری در عالم نیست، ز کمک و همدلی مردم برتری است"

"There is no personal excellence in the world, only assistance and solidarity with others makes us excellent"

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APPENDIX

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APPENDIX A – INTERVIEW SCRIPT

RESEARCH INTERVIEW

"**Towards Modular Construction's Industrialization**: The successful employment of a semi-vertically integrated supply chain by a Prefabricated House Building company."

By S. K. Vafa – 4393732

05.12.2022 – 13.12.2022

Which critical factors steer towards successful synergy within a modular semi-integrated supply chain process?

PART 1: INTRODUCTION.

Interview process:

Welkom en onwijs bedankt voor het deelnemen aan dit interview. Ik zal je een reeks vragen stellen over verschillende onderwerpen. Als iets niet duidelijk is, laat het me dan weten, dan kan ik het altijd herformuleren.

Aller eerst, zou ik je toestemming willen vragen om dit interview op te nemen om niets te missen van wat je zegt, zodat ik er later naar kan verwijzen wanneer ik conclusies zal trekken uit dit interview. De opname zal nooit worden gedeeld buiten de universiteit, noch worden gebruikt voor enig ander doel dan voor mijn eigen informatie.

Het interview is opgedeeld in verschillende onderwerpen die betrekking hebben op afdelingsspecifieke vragen en de ketenintegratie van Lister Buildings. Geen antwoord is fout, dus uit je hoe je wil.

VOORDELEN MODULAIR BOUWEN; tijdsbesparing, lagere arbeidskosten, laag afvalvolume, geschikt voor binnenstedelijk bouwen, flexibel, aanpasbaar, toekomstbestendig, materiaal hout = duurzaam, kwaliteitsgarantie.

We weten ondertussen allemaal wel de voordelen en nadelen van het modulaire of conceptueel bouwen. Maar jullie weten als geen ander dat het bouwproces en de waardeketen een andere vorm aanneemt door met gestandaardiseerde componenten te werken.

Door **de hoge graad van standaardisatie** trekt het proces meer gelijkenissen met het **manufacturing/productie proces** met continue productielijnen, zoals in de auto of scheepsvaart industrie. In deze industrieën werken de verschillende experts en disciplines samen in een **continue geïntegreerd proces**.

Het modulair bouwproces zal **efficiënter** en **productiever** zijn door deze manier van werken ook aan te nemen (of in de vorm van partnerships, aliances). In de literatuur komt deze conclusie regelmatig terug, echter is zijn deze statements nooit bestudeerd in de realiteit.

Het doel van dit interview is om van de verschillende afdelingen van LB de ervaring en inzichten te vergaren over de unieke delivery proces die Lister Buildings aan neemt door in een geïntegreerd proces te werken. De term die vaker valt in de literatuur is the vertical integration of the supply chain, wat een term is uit de manufacturing industrie

Dit is niet gekke gedachte sinds de modulair constructie veel afwijkt van de traditionele constructie naar een gestandaardiseerd systeem en dus ook meer kenmerken opdoet van manufacturing industrieën Uit de DJ Maas workshops hebben we het proces herzien maar ik zie graag vanuit jou hoe jij het proces kent en waar jij betrokken wordt, en wat jouw ervaringen zijn om te werken in een geïntegreerde omgeving. Daarna zullen we wat meer ingaan op je samenwerkingservaringen in dit geïntegreerde systeem. Sounds good?

OK, dan zou ik graag willen beginnen met of je een korte introductie van jezelf zou kunnen geven? Graag met wat achtergrond informatie.

- Wat is het doel van je werk op korte termijn en lange termijn?
- Hoe lang werk je al bij LB en waar ben je momenteel mee bezig?
- Heb je eerdere ervaringen in het werken in een geïntegreerde keten? (serg)
    - Zoja, waar zoal?
        - Welke industrie, Wat was toen je rol, Welke afdelingen waren toen geïntegreerd? Wie zou van wie kunnen leren nog denk je en waarom?
- Wat is de reden dat je bij Lister Buildings bent komen werken, zijn er bepaalde waardes wat jij ook belangrijk vindt of aspecten die je motiveren?
    - Definieert u het product als innovatief? Waarom?
    - Beschouwt u het product als maatwerk? Waarom?
- Kan je me uitleggen wat voor effect het heeft op jouw werk om met een (redelijk) gestandaardiseerd product te werken? (Dev)

Het Lister delivery proces is een net wat ander proces dan in de traditionele bouw, en is door de workshops van DJ Maas ook onder de loop genomen om duidelijkheid te scheppen binnen de organisatie. Hier zie je een delivery proces hoe ik hem heb geïnterpreteerd binnen Lister. Voordat we over het overzicht gaan hebben duiken we even in jullie domein. Nu zou ik het graag even specifiek over je eigen afdeling willen hebben.

- Hoe **ervaar** jij de samenwerkingsverbanden tussen de teams, kan je allereerst per sub-fase aan kunnen geven welke afdeling(en) de grootste invloed op het project hebben (RANK 1-4) en zou je vervolgens lijnen kunnen trekken?
    - Rood voor sterk, Geel voor middel, Groen voor zwak
- Zou je me meer kunnen vertellen over hoe jullie **contact** onderhouden tijdens deze sterkte samenwerkingsverbanden met andere afdelingen?
    - Bepaalde communicatie middelen? (information technologisch)
    - Hoe wordt informatie met elkaar gedeeld
- Wat is de meest **kritische** fase van het project (waar de samenwerking vlekkeloos zou moeten verlopen)? Waarom? Wat komt er bij kijken?
- Zijn er manieren hoe jij dit **anders** zou willen zien? Hoe zou dat eruit zien?
    - Hoe zou in jouw ogen de basis/flow eruit moeten zien om goede samenwerkingen te kunnen faciliteren?

Nu de afdeling specifieke vragen zijn behandelt krijg ik een beter beeld van de stand van zaken en jullie rol in het gehele proces. Zoals ik eerder het overzicht liet zien, zou ik graag nu nog een stap achteruit doen en op proces niveau kijken.

- Zou je meer kunnen vertellen hoe jij het ervaart om in een geïntegreerde omgeving te werken?
  - Wat heb je als **positief ervaren** of als mooie bijkomstigheid?
    - Intern en in concurrentie (competitieve advantage)
  - Wat zie je als **belemmeringen**?
    - Ah en hoe los je die normaal gesproken op?
    - En welke verbeteringen zou je doorvoeren om dit probleem te vermijden?
    - hoe coördineer je met hen als er zich een probleem voordoet?
  - Zijn er aspecten op afdeling niveau wat je zou kunnen verbeteren om de deze moeilijkheden/ algehele samenwerking te verbeteren?

*Capture **sense of need to change** to reach more a more productive and efficient state of operations*

- Hoe heeft het productie proces invloed op hoe de totale waardenketen op dit moment opereert?
  - **(create link between "supply chain" and production)** > Elaborate?
- Hoe ervaar jij op dit moment het productie proces van de modules?
  - Pains, benefits, challenges, gains? Best/Worst
- Op wat voor manier heeft dit effect op hoe jij je werk kan verrichten?

*What they think needs **to change/happen/implemented** to succeed to a more standardized production (improved system design, collaboration and set product configuration)*

- En welke verbeteringen zou je doorvoeren om hogere productiviteit en efficiency te bereiken?
  - Improved system design, collaboration, set product configuration, competency, supply chain management, information sharing, early design freeze etc.

What other support or tool do you need to catalyse this change?

- Welke ondersteuning of welk hulpmiddel denk je nodig om deze verandering te bewerkstellingen?
- Wie zijn er verantwoordelijk voor het regie tussen jullie, of van de supply chain?

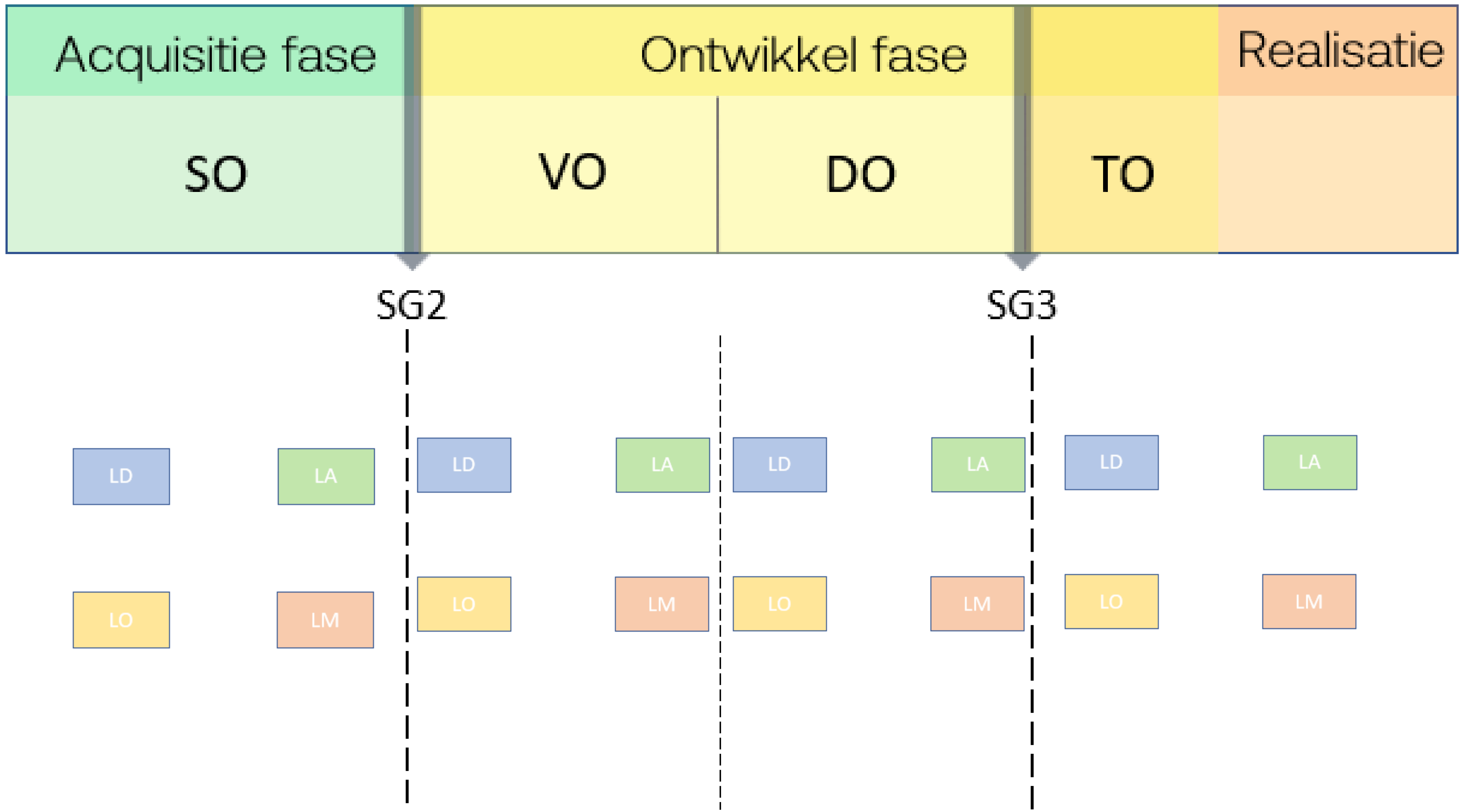
--

EINDE Dat waren alle vragen, bedankt voor je aanwezigheid en je tijd.
Voordat we afronden:

- Heb je zelf nog toevoegingen aan het gesprek wat mij zal helpen in het onderzoek wat ik niet door de vragen op heb kunnen vangen? Dankjewel, heb je zelf nog vragen?

	Concept-to-order (Traditional)	LB1.0					Make-to-stock (Manufacturing)
		- 2	- 1	0	1	2	
Design type	One-of-a-kind project						Repetitive product
Client input	Greatest degree of involvement						Limited to no input
Production rate	Low volume						High volume
Design variety	Design freedom						Standardized
Production type	Unique production process						Continuous assembly line
Supply chain	Fragmented supply chain						Integrated supply chain
Delivery time	Long						Quick
Profit margin	High profit margin/product						Low profit margin/ product
Product configuration	Difficult to control variation						Easy to control variation
Driver	Time driven						Price driven
Innovation	Adapt to market changes						Constant
Focus Perspective	Decision weight: Developer/Designer						Decision weight: Manufacturer
Internal team setup	Short term teams						Long term teams
External Relations	Opportunistic collaboration						Close supplier relationship
Network	Decentralized organized						Centralized organized
Strategy	Agility						Lean

	Concept-to-order (Traditional)	LB2.0					Make-to-stock (Manufacturing)
		- 2	- 1	0	1	2	
Design type	One-of-a-kind project						Repetitive product
Client input	Greatest degree of involvement						Limited to no input
Production rate	Low volume						High volume
Design variety	Design freedom						Standardized
Production type	Unique production process						Continuous assembly line
Supply chain	Fragmented supply chain						Integrated supply chain
Delivery time	Long						Quick
Profit margin	High profit margin/product						Low profit margin/ product
Product configuration	Difficult to control variation						Easy to control variation
Driver	Time driven						Price driven
Innovation	Adapt to market changes						Constant
Focus Perspective	Decision weight: Developer/Designer						Decision weight: Manufacturer
Internal team setup	Short term teams						Long term teams
External Relations	Opportunistic collaboration						Close supplier relationship
Network	Decentralized organized						Centralized organized
Strategy	Agility						Lean



Acquisitie fase
Ontwikkel fase
Realisatie
SO
VO
DO
TO
SG2
SG3
LD
LA
LO
LM

APPENDIX B - OVERVIEW PRODUCTION SYSTEM CHARCATERISTICS

Construction ⟷ Manufacturing

		Project / Design				Product / Make
		CTO	**ETO**	**MTO**	**ATO**	**MTS**
Organization	**Purpose**	Offering clients requirements and vision of the product completely resonates with the end-product.	Improve margins by providing the option to freely customize the product to fit their own unique requirements.	Customizable, relatively expensive product that are specific built to meet the needs of individual customers, although actual design specs have been established.	Set product configuration to shorter lead times and faster order fulfillment workflow. Forecasting to only sourcing whatever inventory is needed for the client.	Low-cost operations, due to high volume assembly line.
	Organisational set-up	Centralized	-	-	-	Decentralized
	Decision weight	Developer/designer	Developer/designer	Developer/designer & manufacturer	Developer/designer & manufacturer	Manufacturer
	Decoupling point	Client	Design	Design/Engineering	Engineering/Manufacturing	Manufacturing
	Innovation	Adapt to market				Continuous improvement through client satifaction
Product	**Clients influence on product**	Total design freedom.	Ability to completely customize product, greatest amount of input into finished product.	Some range to uniquely design product to individual specification, but with fixed design parameters	Customer has limited number of choices to configure end-product	End customer has no input into product. Buys as-is.
	Producing rate	One product	Low volume	Low volume	Higher volume in batches	High volume
	Demand uncertainty	High uncertainty	High uncertainty	Uncertainty	Low uncertainty	Stable demand, low degree of error. Accurate historical demand info available.
	Profit margin per product	High margin	High margin	High margin	Low profit margin, competitive environments	Low profit margin
	Design variety	Highest design freedom	Higher design freedom	Reasonably	Limited, but gives client idea of design freedom	High volumes Low degree of/No design variation
	Delivery time	Long	Long	Manageable, not instant available	Relatively quick, depends on amount of customization	Quick
	Product configuration	-	-	Standardized modular components + additional elements to specifically meet individual clients' desires.	Modular approach: Standardized comp produced efficient in batch & assembled to meet individual needs.	Highest form of standardization
	Other	Project environment	• Each product is different to the last • Existing designs maybe modified, otherwise new designs are developed	Producing high quality and individually customizable product.	• Typically for higher priced goods, assembled to customer specifics. • Frequently updated with latest techs	
Production	**Production type**	Unique process	If possible, existing assembly-lines are modified to order, otherwise new ones are created	Mix of continuous and unique assembly lines	Several continuous assembly lines to be able to configure end product	Continuous assembly line
	Supply chain collaboration	Fragmented supply chain	Fragmented supply chain	Semi-integrated	Integrated supply chain & long-term commitment	Integrated supply chain & long-term commitment
	Storage	No	No	No, or low.	Yes	Yes
	Supply Chain Strategy	• **AGILITY**: for competitive. adv. due to changing uncertain client needs. • *Innovation: adapt to market* • *CHALLENGE*: Rapid information visibility and collaborative supply chain interactions are hard owing to customer requirements.	• **AGILITY** • *Innovation: adapt to market* • New product development • Customer satisfaction • Information management	• **LEAGILITY:** Focus on attracting and maintaining new customers > Less opportunity to practice **LEAN** • *Innovation: adapt to market* • *CHALLENGE*: To achieve efficiency, you need collaborative partnerships, but you also need the freedom to explore alternatives.	• **LEAGILITY:** business wide capability to react quickly to market changes, enabled among other things by flexible processes • *Innovation: continuous* • *CHALLENGE*: Low pricing, quick delivery, whilst offering customization.	• **LEAN:** efficiency (to eliminate waste) • *Innovation: continuous* • Close relationships with internal and external relations • Cooperative • Minimizing costs
	Others	• Flexibility in production • Highly skilled labour • Highest quality of product		• labour skills > automation • No distributor or retailer, directly from manufacturer > faster response to customer	• Small number of intermediaries: or retailers or direct customer	• High degree of automation • Low costs • Relies heavily on distribution centres and retailers to deliver to customer

APPENDIX C - LITERATURE REVIEW FOR PRELIMINARY CSF-LIST

Author(s)	Literature title	Categories
Holland et al. (2000)	*Critical success factors for cross-functional teamwork in new product development*	Task design, Internal processes, Group composition, External processes, Organizational context, Group psychosocial traits
Azar et al. (2012)	*Modular v. Stick-Built Construction: Identification of Critical Decision-Making Factors*	Design-related factors, Module-related factors, Manufacturing unit, Organization's readiness, Technology-related factors, Owner's perspective, Project risk factors, Sustainability requirements
Ismail et al. (2012)	*Management Factors for Successful IBS Projects Implementation*	–
O'Connor et al. (2014)	*Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization*	–
Choi et al. (2017)	*Opportunities and challenges of modular methods in dense urban environment*	Stakeholders, Technology, Design, Procurement, Collaboraiton, Culture
Li et al. (2018)	*Critical Success Factors for Project Planning and Control in Prefabrication Housing Production: A China Study*	Experience and Knowledge, Competence of the project manager, technology and method, external environment, experience and knowledge, information, communication and collaboration
Yuen et al. (2019)	*Critical success factors of supply chain integration in container shipping: an application of resource based view theory*	Relationship management, Information management, Organizational commitment, strategic alignment, Performance management
Cheng et al. (2020)	*Establishment of Critical Success Factors for Construction Partnering*	Adequate resourcing, Management support, Mutual Thrust, Long-term-commitment, Coordination, Creativity, Eff. Communication, Conflict resolution, Compatible goals
Wuni & Shen (2020.02)	*Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle*	–
Wuni et al. (2020.07)	*Risks of modular integrated construction: A review and future research directions*	Schedule Risk, Supply chain risks, Ergonomically risks, implementation risks, structural risks
Wuni & Shen (2020.10)	*Critical success factors for modular integrated construction projects: a review*	Phase related: conception, planning, design, procurement, construction
Wuni & Shen (2021.09)	*Exploring critical success determinants for supply chain management in MiC projects*	Project strategy, stakeholder management, process management, risk management, competency
	"Critical factors for successful implementation of just-in-time concept in modular integrated construction: A systematic review and meta-analysis"	Managerial, educational & knowledge, Technical, Financial, Culture & Human, Skills & Expertise, Logistics
Tsz Wai et al. (2021)	*A critical analysis of benefits and challenges of implementing modular integrated construction*	Project characteristics, transportation aspect, stakeholder collaboration
Wuni & Shen (2021)	*Developing critical success factors for integration in modular construction projects in Hong Kong*	Competence & early commitment, Effective supply chain management, Collaboration and information management
Wuni et al. (2022)	*Quantitative evaluation and ranking of the critical success factors for modular integrated construction projects*	Adequate technical capability and infrastructure, early commitment, effective stakeholder and supply chain management, standardization and benchmarking

APPENDIX D - DEVELOPING PRELIMINARY CSF-LIST

communiaction / stakeholder management	competence	culture	supply chain management
CF34 Collaboration among supply chain members	**CF27 Knowledge and awareness of JIT**	**CF25 Employee morale and motivation**	**CF3 Extensive planning and scheduling**
CF35 Communication and information sharing	**CF29 Education and research**	**CF23 Leadership and its managerial aspects**	**CF1 Top management**
CSF4 Adequate knowledge and experience of the project team	**CF28 Training**	**CF26 Trust among supply chain members**	**CF4 Stakeholder management**
CSF7 Early and active involvement of critical project stakeholders	**CSF1 Early design completion and freezing**	**CF22 Culture and human attitude**	**CF5 Integrating risk management and supply chain management**
CSF9 Extensive upfront planning for circular modular construction projects	**CSF3 Effective leadership and support of a specialist contractor**	**CF24 Knowledge sharing**	**CF9 Organisational structure**
CSF14 Adequate lead time for the bespoke processes of circular modular co	**CSF6 Design for manufacture, assembly, and circular economy**	**CSF3 Organizational readiness and familiarity with MiC**	**CSF2 Early understanding and commitment of the client**
CSF18 Use of collaborative procurement system and contracting	**CSF12 Effective management of critical tolerances between interfaces**	**CSF10 Top management support and commitment**	**CSF5 Collaborative working and information sharing among project teams**
CSF21 Use of hedging strategies and transport delay avoidance	**CSF13 Effective coordination of onsite and offsite work packages**		**CSF8 Effective coordination and integration of stakeholders**
CSF22 Inventory management and control	**CSF15 Use of just-in-time delivery arrangement**		**CSF9 Leveraging information from demolition and design lifecycle stages**
CSF2 Effective communication and information sharing	**CSF16 Suitable site characteristics and layout**		**CSF9 Using suitable structural system and construction material**
CSF5 Early involvement of critical supply chain stakeholders	**CSF20 Effective use of building information modeling**		**CSF17 Integrating circular economy principles into the supply chain of modular construction projec**
CSF13 Information and communication technology solutions	CSF3 Accurate design, early design freeze and timely owner's approval		**CSF18 Early engagement of certification body for factory inspection**
CSF1 Good working collaboration, effective communication, and information sharing among	CSF11 Adequate relevant experience and knowledge of contractor, designer, and manufacturer of MiC projects		**CSF23 Effective use of document management system**
CSF8 Early and effective use of information and communication technology	CSF13 Top management support and early involvement of in the MiC supply chain		**CSF1 Design for supply chain management**
CSF17 Alignment of modules architecture and long -term collaboration among fabricators, s	CSF18 Early advice and modularization consideration from MiC design professionals and experts		**CSF4 Seamless integration and coordination of supply chain**
CSF16 Long-term relationship and partnership	CSF1 Fabricator experience and capabilities in modules design and production		**CSF7 Effective coordination and management of stakeholders**
CSF3 Good working collaboration, communication and information sharing among project p	CSF2 Robust drawing specifications and early design freeze		**CSF16 Long-term relationship and partnership**
CSF2 Good working collaboration, effective communication and information sharing among	CSF9 Early involvement of modules suppliers and fabricators		CSF2 Improved supply chain coordination and management
CSF3 Effective stakeholder management	CSF11 Early advice and consideration from MiC design experts and professionals		CSF4 Fully-integrated approach and involvement of key participants throughout the project
CSF5 Early engagement of key players such as designers, engineers, fabricators, and contr	CSF20 Support and early involvement of top management in supply chain decision making		CSF7 Extensive MiC project planning, scheduling and control
CSF9 Effective use of information and communication technology (e.g. BIM)	CSF21 Appreciation of key early decisions and their implication between all parties involved		CSF9 Effective stakeholder MiC management starting with clearly defined goals and priorities of all involved stakeholders
F7 Involvement of contractors and manufacturers during the design stage [9]	CSF24 Early completion and cost savings recognition		*CSF17 Alignment of modules architecture and long -term collaboration among fabricators, suppliers, designers, subcon*
F11 Involvement of the designer during the production and construction stage [46]	CSF#4 Timely Design Freeze		CSF5 Effective coordination of the supply chain segments
F14 Effective communication among participants [9,55,56]	CSF#9 Contractor Leadership		CSF6 Availability and active involvement of key project team members from the earliest stages of the project
F16 Information sharing among participants [10,57]	CSF#10 Contractor Experience		CSF7 Extensive project planning, scheduling and control
F20 Adoption of Information and communication technology (ICT) such as building informatio	CSF1 Robust design specifications, accurate drawings, and early design freeze		CSF14 Effective coordination and management of stakeholders
	CSF8 Adequate experience and technical knowledge of key participants		CSF15 Effective coordination of on-site and off-site trades
	F1 Designers' experience of PHP [26,45]		CSF19 Suitable procurement strategy and contracting
	F2 Manufacturer's experience of PHP [5,23]		CSF22 Effective use of information and communication technology (e.g. BIM)
	F3 Project manager's ability to solve problems [54]		CSF23 Effective supply chain and execution risk management
	F4 The maturity of techniques used in the detailed design phase [11,58]		CSF25 Module envelope limitations
	F6 Skills and knowledge of labors [15,17,39,53]		CSF#2 Alignment on Drivers
			CSF5 Early engagement of key players such as designers, engineers, fabricators, and contractor
			F12 Efficient coordination between off-site and on-site [59]

Communication	Collaboration	Information Sharing	Culture
CSF1 Good working collaboration, effective communication,	CSF1 Good working collaboration, effective communication, and information sharing ar	CSF1 Good working collaboration, effective communication, and information sharing among MiC project pa	CSF2 Trust among supply chain members
CSF2 Effective communication and information sharing	CSF2 Good working collaboration, effective communication and information sharing am	CSF2 Effective communication and information sharing	CSF22 Culture and human attitude
CSF2 Good working collaboration, effective communication	CSF3 Good working collaboration, communication and information sharing among proj	CSF2 Good working collaboration, effective communication and information sharing among project partici	CSF25 Employee morale and motivation
CSF3 Good working collaboration, communication and infor	CSF5 Collaborative working and information sharing among project teams	CSF3 Good working collaboration, communication and information sharing among project participants	CSF10 Top management support and commitment
CSF14 Effective communication among participants [9,55,56]	CSF9 Extensive upfront planning for circular modular construction projects	CSF5 Collaborative working and information sharing among project teams	CSF1 Top management
CSF35 Communication and information sharing	CSF14 Adequate lead time for the bespoke processes of circular modular construction p	CSF8 Early and effective use of information and communication technology	CSF2 Early understanding and commitment of the client
	CSF16 Long-term relationship and partnership	CSF9 Effective use of information and communication technology (e.g. BIM)	CSF13 Top management support and early involvement of in the MiC supply chain
	CSF17 Alignment of modules architecture and long -term collaboration among fabricatc	CSF13 Information and communication technology solutions	CSF20 Support and early involvement of top management in supply chain decision making
	CSF18 Use of collaborative procurement system and contracting	CSF16 Information sharing among participants	
	CSF34 Collaboration among supply chain members	CSF20 Adoption of Information and communication technology (ICT) such as building information modelin	
	CSF11 Involvement of the designer during the production and construction stage [46]	CSF22 Effective use of information and communication technology (e.g. BIM)	
	CSF4 Fully-integrated approach and involvement of key participants throughout the pro	CSF22 Inventory management and control	
	CSF5 Early engagement of key players such as designers, engineers, fabricators, and contractor	CSF24 Knowledge sharing	
	CSF5 Early involvement of critical supply chain stakeholders	CSF35 Communication and information sharing	
	CSF7 Early and active involvement of critical project stakeholders		
	CSF7 Involvement of contractors and manufacturers during the design stage [9]		
	CSF9 Early involvement of modules suppliers and fabricators		
	CSF11 Early advice and consideration from MiC design experts and professionals		
Effective communication		Frequent information sharing	
		Use of information and communication technology (BIM)	
	Good working collaboration among participants		
	Long-term partnership		
	Continious collaboration between parties throughout the phases		
	Early involvement of key players (in design phase and producton phase)		

Experience	Early Design Freeze	Set specifications
CSF1 Designers' experience of PHP [26,45]	CSF1 Early design completion and freezing	CSF2 Robust drawing specifications and early design freeze
CSF1 Fabricator experience and capabilities in modules design and	CSF2 Robust drawing specifications and early design freeze	CSF1 Robust design specifications, accurate drawings, and early design freeze
CSF2 Manufacturer's experience of PHP [5,23]	CSF1 Robust design specifications, accurate drawings, and early d	CSF3 Accurate design, early design freeze and timely owner's approval
CSF3 Effective leadership and support of a specialist contractor	CSF3 Accurate design, early design freeze and timely owner's appr	CSF6 Design for manufacture, assembly, and circular economy
CSF3 Project manager's ability to solve problems [54]	CSF4 Timely Design Freeze	CSF25 Module envelope limitations
CSF3 Organizational readiness and familiarity with MiC		CSF16 Suitable site characteristics and layout
CSF4 Adequate knowledge and experience of the project team		
CSF4 The maturity of techniques used in the detailed design phase		
CSF6 Skills and knowledge of labors [15,17,39,53]		
CSF8 Adequate experience and technical knowledge of key participants		
CSF9 Contractor Leadership		
CSF10 Contractor Experience		
CSF11 Adequate relevant experience and knowledge of contractor		
CSF20 Effective use of building information modeling (?)		
Adequate experience and knowledge	Early design freeze	Defined specifications of design
Organizational readiness and familiarity with modular const		Accurate drawings
maturity of techniques		

Coordination	Supply Chain Structure (integrated)	Stakeholder Management = Involvement
CSF2 Alignment on Drivers	CSF1 Design for supply chain management	CSF3 Effective stakeholder management
CSF2 Improved supply chain coordination and management		CSF12 Effective management of critical tolerances between interfaces
CSF3 Extensive planning and scheduling	CSF4 Seamless integration and coordination of supply chain	CSF18 Early advice and modularization consideration from MiC design professionals and experts
CSF5 Effective coordination of the supply chain segments	CSF5 Integrating risk management and supply chain management	CSF12 Effective management of critical tolerances between interfaces
CSF7 Effective coordination and management of stakeholders	CSF8 Effective coordination and integration of stakeholders	
CSF7 Extensive MiC project planning, scheduling and control	CSF23 Effective supply chain and execution risk management	
CSF7 Extensive project planning, scheduling and control	CSF16 Long-term relationship and partnership	
CSF8 Effective coordination and integration of stakeholders		
CSF12 Efficient coordination between off-site and on-site [59]		
CSF14 Effective coordination and management of stakeholders		
CSF15 Effective coordination of on-site and off-site trades		
CSF13 Effective coordination of onsite and offsite work packages		
CF23 Leadership and its managerial aspects		
Coordination between design and production	Organizational structure	Effective management between interfaces
Management of cross-functional teams		Stakeholder management
Early planning and scheduling		
	Coordination between interfaces (design and production)	
	Management between cross-fucntional teams	
	Early planning and scheduling	
	organizational structure	

APPENDIX E - CODING INTERVIEWS

DEP.	CATEGORY	POS/NEG	CSF	Comment
LD	COLLABORATION	IDEAL	Early involvement of key players	In SO zou je in principe nog een externe architect erbij willen hebben, om ervoor tezorgen om juist buiten die kaders te gaan, dan heb je meer syteem ontwikkeling nodig. Bij koffiefabriek bijv.
LA	COLLABORATION	IDEAL	Early involvement of key players	Je wil eigenlijk iemand zoals esther, vivian of frank (niet hem perse, maar zijn capaciteiten) een engineer wil je aan tafel hebben bij elk koffiefabriek overleg wat maar iets te maken heeft met het gebouw. Hierdoor kan hij/zij het vertalen r
LM	COLLABORATION	IDEAL	Early involvement of key players	Wij zijn hier dagelijks bezig met het bouwen van die modules, wij weten als gene ander hoe je een module wel of niet kan maken. Je hebt kaders nodig om te bepalen war die module aan moet voldoen, maar als je binnen die kaders je kan
LO	COLLABORATION	IDEAL	Early involvement of key players	Eigenlijk zou je al veel eerder iemand van productie veel eerder aangehaakt moet worden en op de hoogte te zijn wat er speelt. Nu omdat we het zo opgedeeld hebben zijn er mensen die te laat worden ingeschakeld.
LD	COLLABORATION	NEG	Early involvement of key players	Want LO zit ook in SO en VO aan tafel, weliswaar onbewust gebeurt dat wel. Misschien zou je dat bewuster moeten doen om ook mensen aan tafel bewuster te laten zijn van dat het project proces en het product proces
LD	COLLABORATION	NEG	Early involvement of key players	producent van de modules dus niet op tijd aanwezig was tijdens het ontwikkelproces, maar ze waren aanwezig maar dan wijzigden weer dingen.
LD	COLLABORATION	NEG	Early involvement of key players	Ik denk dat de contactmomenten aan de acquisitie fase steeds beter worden tussen LO en LD en dat je daar ook weer gegroeid als bedrijf. Dat we ook steeds beter weten wat we wel en niet moeten doen. Nee
LA	COLLABORATION	NEG	Early involvement of key players	Het liefste zien wij veel eerder al In het traject, zoals we nu bijvoorbeeld in Oss aan de raadhuislaan of in Bergen op Zoom. Of noem het zo maar op. Van die stedelijke ontwikkelingen waar je zelf al eigenlijk de de afmetingen van het gebou
LD	COLLABORATION	POS	Early involvement of key players	Nou wat super relaxed is dat wij in SO dat het contact heel laagdrempelig is tussen ons en de architecten en de systeemontwikkelaar. Helemaal van het begin van fase trekken we gewoon even één van die jongens aan de mouw met de vra
LO	COLLABORATION	neg	Early involvement of key players	Nu merk je dat LO pas aan het einde bij projecten nog heel erg met LA en LM proberen nog voor het project op de rit te krijgen. Ideaal zou zijn als we vanaf het begin vanuit de maakkant moeten berederen. Eigenlijk zou 'deze' paars moete
LA	COLLABORATION	IDEAL	Established collaboration structur	Ja wat wij fijn zouden vinden als LA, is dat wij een Vo en DO deadline, wat wij fijn vinden is een ½ DO deadline, een soort tussenstand document. Dat iedereen zijn structuren aanmaakt, een soort proeftoets. Dit is intern een moment en m
LM	COLLABORATION	IDEAL	Established collaboration structur	De contactmomenten moet je behouden voor de speciale/aparte details maar voor het gestandaardiseerde product zou dat in principe niet meer hoeven. Idealieter, als alles uitgekristalleiseerd en uitgeeingeerd is dat over de moudle niet
LA	COLLABORATION	NEG	Established collaboration structur	Nee, zie je daarmee dat proces van Dirk Jan is daar Natuurlijk ook van belang is. Ja, Maar we hebben eigenlijk nog niet echt op vaste manier van werken tussen de teams! Binnen opportunity helemaal niet, want dan hebben we het over ee
LA	COLLABORATION	NEG	Established collaboration structur	Als we aan een schetsontwerp gaan beginnen dan hebben we nog niet echt een werkstructuur voor die fase. Bijv. als ik nu kijk naar amaliazorg, KF (Dat was een tender), is daar ook nog niet echt een hele vaste werkstructuur.
LA	COLLABORATION	NEG	Established collaboration structur	VO, als we echt gaan starten met de samenwerking met adviseurs, dan hebben we al wel veel betere structuur tussen ontwikkelteams en ontwerpteams. Dan doen de afspraken die je maakt met externe partijen dat. Er is ook een duidelijl
LA	COLLABORATION	NEG	Established collaboration structur	We willen eigenlijk NIET EENS WETEN waar LO qua verbeteringen hebben want dan denken wij weet, heh shit! Dat hadden we ook kunnen gebruiken... en dat kan dan niet.
LM	COLLABORATION	NEG	Established collaboration structur	- Geen relatie met systeemontwikkeling:
LM	COLLABORATION	NEG	Established collaboration structur	Iedereen is met heel veel verschillende dingen bezig. We hebben soms geen tijd voor elkaar, terwijl we juist veel moeten overleggen.
LM	COLLABORATION	pos	Established collaboration structur	We hebben een vergaderstructuur. Maar goed, we zetten ook naast of achter elkaar, dus die het rijtje om een aan Je kunt overleggen.
LD	COLLABORATION	ideal	Established collaboration structur	ik denk dat we naar een systematiek moeten gaan waarin je dat van te voren duidelijk afspreekt. Als er een acq aankomt, die voldoet aan de volgende voorwaardes dan zullen wij elkaar op die en die momenten spreken. En dan verwacht
LA	COLLABORATION	POS	Established collaboration structur	Dalijk zit ik met Martijn over de lessons learned van Milsbeek, dat die lessen ook worden opgepakt voor koffiefabriek. LA<>LD in VO sterker.
LA	COLLABORATION	POS	Established collaboration structur	"Lessons Learned" met Martijn van LO > het is een document met foto's en beschrijvingen van welk onderdeel is en wat het had moeten zijn, of wat willen we dat het uiteindelijk wordt. Dat we daaruit de lessen konden trekken en dat we
LO	COLLABORATION	POS	Established collaboration structur	. We zijn nu begonnen met Lessons Learned van een aantal prjecten. Zodat we de lessen en hobbels meenemen naar de systeemontwikkeling dat we daar op kunnen voortboorduren. Daar kwam ene lijst uit.
LM	COLLABORATION	POS	Established collaboration structur	Ketenoverleg > projectmatig, wat zit er aan tekomen en afstemmen van activiteiten en mensen en processen. We hebben niet zoveel projecten maar het is voor nu genoeg. Projectoverlegm & MT overleg
LA	COLLABORATION	NEG	Established collaboration structur	Robert en ik hebben met name bij TO in milsbeek echt geprobeerd om de werkvoorbereiding om Frank, Jeroen, Vivian en Nick blokker aan tafel te krijgen om input te krijgen wat zij verwachten van ons voor een TO. Wat hebben jullie nodi
LD	COLLABORATION	POS	Collaborative working environme	POS: je hebt je peers heel snel aan tafel, dus je hoeft niet meer naartoe te rijden naar architectenbureau die met andere systemen in een andere sharepoint map op een andere manier samenwerkt.
LA	COLLABORATION	POS	Collaborative working environme	Het voordeel van LB, en dat is het idee ook, dat alles onder LB valt, is dat je hele korte lijntjes hebt en elkaar redelijk vaak ziet. Je opdrachtgever zit een paar bureau's naast je, dat is makkelijk. Met LM is dat iets lastiger omdat de fabriek ir
LM	COLLABORATION	POS	Collaborative working environme	Lijntjes zijn kort. Kunnen we zeker beter doen, binnen het bedrijf ervaar ik de wil en is iedereen er mee bezig, je krijgt namelijk van ene fase naar andere fase en daar spelen weer alle belangen in mee.
LA	COLLABORATION	NEG	Collaborative working environme	Je moet echt in gesprek met Serge en Jeroen, de wereld DB en Weert, zijn ondanks dat we een bedrijf zijn, twee verschillende werelden.
LO	COLLABORATION	NEG	Collaborative working environme	Kijk we hebben te maken met een geografische verspreding van het bedrijf en de mensen. er onvoldoende samenwerking en interactie.
LO	COLLABORATION	NEG	Collaborative working environme	. Het verschil zit het in de lijnen die korter zijn en je kan elkaar direct betrekken. Aan de andere kant heb ik het idee dat we er niet optimaal gebruik van maken.
LM	COLLABORATION	NEG	Collaborative working environme	Kijk, de afstand tussen Den Bosch en Weert maakt het niet makkelijk want je loopt niet perse snel binnen bij elkaar.
LM	COLLABORATION	NEG	Collaborative working environme	De afstand tussen Weert en Den Bosch werkt daar ook niet echt aan mee. Dus dat is ook wel een ding, daar hebben we stiekem meer last van dan we denken. Belemmerend om sneller achter elkaars ideeën en beslissingen te komen, geen
LA	COLLABORATION	neg	Collaborative working environme	Dat er twee verschillende locaties izjn. We hebben een kakntoor in den bosch uit alle regios van het land, en je hebt een fabriek in weert met collega's uit die omgeving.
LO	COLLABORATION	NEG	Collaborative working environme	Ik vind toch wel fysieke aanwezigheid hier lastig is na corona, Dat je niet samen in een ruimte aan iets werk. Ook het niet zien van ons werk is lastig. Al die mooie tekeningen, mooie presentaties die we maken.
LA	COLLABORATION	NEG	Collaborative working environme	Het zijn een stuk stuggere mensen, echt waar. Ik ervaar dat al een half jaar. Ik zelf ben een druppel op een gloeiende plaat, ik krijg soms dingen naar mijn hoofd vab "ah heb je die architect weer" op die toon..
LD	COLLABORATION	POS	long term partnership	Ja, elkaar al kent samenwerking die repeteert gaat ook steeds beter, dus Dat is dat zijn allemaal. Dat is daar zitten eigenlijk Alleen maar voordelen aan het ene, hè?
LA	COLLABORATION	POS	long term partnership	Samenwerking LA<>LD<>LO gaat goed, we voelen elkaar goed aan, korte gesprekken en informeel is fijn.
LA	COLLABORATION	POS	long term partnership	Lange termijn = we hebben zoveel nog te winnen in het systeem. We hebben een mooie start gemaakt en hebben we een LO afdeling en daar zou het gestald moeten zijn. Dat neemt niet weg dat er een wisselwerking moet zijn tussen LA e
LM	COLLABORATION	POS	long term partnership	Je brgijpt erlkaar veel beter, het zijn totaal verschilllende disciplines, waarin iedereen zijn ei kwijt kan en lerend vemogen steeds hoger wordt omdat je veel van elkaars vakgebieden meekrijgt.
LD	COLLABORATION	pos	long term partnership	Tegelijkertijd geeft het je zekerheid, je hebt je vriendjes aan tafel waardoor je een daadkracht hebt geïntegreerd kan aanbieden aan een klant. Maakt je veel stabieler en daadkrachtiger aan tafel. Het heeft voor en nadelen
LA	COLLABORATION	pos	long term partnership	Dat reflecteren en ze lerende vermogen, we ontwikkelen een systeem met een vast team vervolgen gaan we een project bouwen en ontwikkelen met datzelfde team, intern maar ook adviseurs. We ontwikkelen een systeem, ontwerpen e
LA	COMMUNICATION	POS	Established collaboration structur	Ontwikkelteam = intern (LA en LD), Ontwerpteam is (LD, LA en met externe en beiden)
LA	COMMUNICATION	pos	Established collaboration structur	. Maar ook andersom, als wij dingen tegenkomen die geintegreerd kunnen worden in systeem wat makkelijker is, dan communiceren we dat ook naar LO.
LA	COMMUNICATION	POS	Established collaboration structur	Wij zien elkaar dagenlijks, elke dag hebben wij drie dagen in de week, veel vergaderingen en meetings die barthold eigenlijk veel heeft. Voor de rest is het Teams of telefonisch.
LA	COMMUNICATION	POS	Established collaboration structur	Met LO hebben we echt een weekstart met agenda's naast elkaar zetten, en donderdag dat we gezamenlijk een onderwerp doornemen. Bijv. we zijn nu een Lister documenten lijst (welke documenten lever je aan in welke fase) en in welk

LM	COMMUNICATION	POS	Established collaboration structure	De communicatie met Thijs als developer en voor projectMilsbeek als projectmanager gaat ook met wekendlijks overleg (mail of telefoon of teams). Met milsbeek ook VSB, en architecture hebben we een overleg structuur
LD	COMMUNICATION	NEG	Shared understanding and clear messaging	Wat je wel ziet is dat, Maar dat gaat dus over definities. Die definitie kun je zo houden, maar Als je Het gaat over modulair bouwen, dan is een VO of een SO heel anders qua product dan wat je traditioneel gewend bent.
LA	COMMUNICATION	neg	Shared understanding and clear messaging	. Maar je merkt bij KF en Milsbeek dat het moielik is om te standardiseren, want op welk niveau heb je het dan? Over een plank of op module iveau, dat heeft grote gevolgen met hoe je het maakt in de fabriek. De afstemming en het overc
LO	COMMUNICATION	IDEAL	Shared understanding and clear messaging	Het stadium nu is omdat we het product nog niet uitontwikkeld hebben werken wij samen maar ook egscheiden want we moeten het verschil bewaren tussen wat het project is en wat het product developemnt is. Om die gescheiden te ho
LD	COMMUNICATION	IDEAL	Shared understanding and clear messaging	> Hier komt de techniek al veel eerder om de hoek kijken. Dus je definitie van wat een SO moet inhouden is met modulair bouwen eigenlijk anders. Dus zeg maar, zoals je standaard documenten-lijst had van SO, VO, DO, TO conform de DN
LM	COMMUNICATION	NEG	Shared understanding and clear messaging	Langer samenwerken en goed luisteren. En dat zal echt oeten gebeuren anders kom je niet naar een efficiente fabrieksomgeving.
LA	COMMUNICATION	IDEAL	Shared understanding and clear messaging	Die standaard kennis is per project is heel handig en helder naar LD maar ook naar LM. Zij moeten ook begrijpen waarom we sommige dingen tekenen waarom we zo tekenen, wat natuurlijk slimmer en beter kan.
LD	COMMUNICATION	pos	Shared understanding and clear messaging	. Dus het maakt je makkelijker wat betreft zekerheid en snelheid, dus je weet veel eerder wat iets kost, je kan veel sneller een proces door.
LD	COMMUNICATION	NEG	effective communication	Maar op dit moment zie je nog dat eigenlijk Lister manufacturing die rol aan tafel van "wow ik moet het straks gaan maken" ze nog niet aan tafel eerder schuiven. Die slaat nu nog niet met zijn vuist vertalen in dat ontwerpfase van "hey lu
LD	COMMUNICATION	NEG	effective communication	o En trainingen dus dat vaker benoemen en vaker zeggen en vaker met elkaar doen.
LA	COMMUNICATION	neg	effective communication	Nee ik vind niet dat we op elkaar zijn ingespeeld. W ezijn een jong bedrijf en we doen nog veel te veel op kracht, er zit geen souplesse en geen automatisme in.
LA	COMMUNICATION	NEG	effective communication	Kost enorm veel tijd om dat in beeld in krijgen op een tekening en helder te structureren op module niveau! Dit noemen we het module matrix; de manier hoe zij dit project zien.
LO	COMMUNICATION	NEG	effective communication	Ook was manufacturing te lief geweest om NEE te zeggen, of JA MAAR.
LM	COMMUNICATION	NEG	effective communication	Want als een van de volgende vindt dat dat een onjuist besluit is geweest dat je met elkaar hierover kan praten waarom hij dat heeft besloten en waarom dat niet een gelukkig besluit is geweest. Ik merk zeker de wil omdat op een goede r
LA	COMMUNICATION	NEG	effective communication	Wat ik heel erg heb gemerkt bij de meeting bij DJ Maas, is dat inhoudelijk het gesprek voeren van wanneer is wie nou vernatwoorldijk voor welk onderdeel of fase. Die gesprekken gaven mij echt inzichten waar de pijnpunten liggen: die kl
LM	INFORMATION SHARING	IDEAL	early and effective use of information/comm	Als je kijkt naar de productie industrie heb je het over systemen. Je hebt het over het uitkauwen van systemen, het over goed ERP landschap waarin. Alles zakelijk achter de komma gedefinieerd in kwaliteitsprocessen en engineeringsproc
LD	INFORMATION SHARING	NEG	early and effective use of information/comm	Ik denk wel dat je een productie flowchart van een gestandaardiseerd product hieraan toe zou moeten voegen en dat op elkaar zou moeten klikken, en dat zou meten clashen "welke informatie heb ik wanneer nodig om het proces goed te
LA	INFORMATION SHARING	NEG	early and effective use of information/comm	2e waar wij heel erg mee worstelen is onze samenwerking in BIM. He wij zijn een geintegreerde keten: ont, ontwerp, realisatie en beheer. Doen we in Revit en vanuit dat Revit model hebben we een basis voor de productie en uiteindelijk
LO	INFORMATION SHARING	neg	early and effective use of information/comm	De mensen die nu rondlopen hebben we twee externen aangenomen als eerste stap in de goede richting. Wat mij vebaast is dat er propaganda gedaan moet worden om mensen te overtuigen van de waarde van technologische.
LO	INFORMATION SHARING	NEG	early and effective use of information/comm	Grappig genoeg zit dat gat ook in BIM. Op de een of andere manier blijft er een gat
LM	INFORMATION SHARING	NEG	early and effective use of information/comm	We zouden veel meer gebruik moeten maken van digitalisering, en ook in de fabricatie. - Er is pas eigenlijk sinds een half jaar begrip voor wat ik net heb verteld
LA	INFORMATION SHARING	POS	early and effective use of information/comm	Dat is meer traditioneel en nu werken we ook inACC voor KF in DO om met PBT en CLTS en LA een gecoördineerd revit model tot DO te brengen. Daarin doen we oook clashdetecties en spreken we af wat eropgepakt moet worden. Dat is (
LA	INFORMATION SHARING	POS	early and effective use of information/comm	Ja we zijn erg druk bezig met LA het opzetten van platformen met BIM. Zo om met onze partners te werken en de constructeur, we zijn daar druk mee om daar geintegreerd systeem op te zetten om die samenwerking makkelijker te make
LD	INFORMATION SHARING	NEG	frequent information/knowledge sharing	Als van iedereen de input bij DO heel goed is, van bijv ook LM, en die overgang, dan heb je al eerder In het proces zekerheid over die 3 punten.
LD	INFORMATION SHARING	NEG	frequent information/knowledge sharing	We meoten extreem goede informatie en kennis krijgen over hoe nou de module gemaakt wordt > productie
LD	INFORMATION SHARING	NEG	frequent information/knowledge sharing	door al bij SO de informatie te hebben om te kijken of een project interessant voor ons is.
LM	INFORMATION SHARING	NEG	frequent information/knowledge sharing	Dus zij hebben wel veel informatie van LM nodig om het product te kunnen verkopen mar daar is onduidelijkheid over. Geen vaste kostprijs. Dat is erg belangrijk, maar op dat punt zijn we nog niet.
LA	INFORMATION SHARING	POS	frequent information/knowledge sharing	Communicatie, dat iedereen weet dat bij bepaalde projecten wat er speelt.
LA	INFORMATION SHARING	neg	frequent information/knowledge sharing	Jazeker, voor de SO heb je echt niet een uitgekauwt PvE nodig een guideline, maar als je aan het VO gaat beginnen wil je wel een goed uitgewerkt PvE willen. Nee het is niet strakker of beter is dan een tarditioneel PvE ik denk juist makkel
LA	INFORMATION SHARING	neg	frequent information/knowledge sharing	Heldere uitgangspunten, wat wij meestal missen is een helder PvE.
LA	INFORMATION SHARING	neg	frequent information/knowledge sharing	Wat heel erg zou helpen, denk ik, aan de voorkant waar als Lister nog niet zo goed in zijn. In de voorkanteen afgekadert PvE opstellen: afwerkingen van woningen, technische en prgrammatische eisen van woningen, dat helpt wel als we da
LA	INFORMATION SHARING	POS	frequent information/knowledge sharing	Wij initiëren het halve document dat we een half DO willen en we vragen voor die datum ene rapport wat iedereen op dat moment weet en wat er is. En dat helpt heel erg in het beeld krijgen wat er geleverd gaat worden. Dat levert mind

Department	CSF	POS/NEG	Comment
LD	MORALE/MOTIVATION	NEG	Ontkomt er nooit helemaal aan dat mensen hun mening geven. Het zijn ook Nederlanders dus ook heel erg de Nederlandse cultuur allemaal ja wat te zeggen willen hebben, dus soms polderen we (= Iedereen brengt gelijkwaardig iets in), terwijl misschien in die bepaalde fase 3 van de 5 mensen aan tafel hun mening er echt veel minder toe doet.
LD	MORALE/MOTIVATION	POS	Dat vond ik sterk aan Lister dat ik als ontwikkelingsmanager kan opereren en een concept kan bedenken aan de voorkant en een beleving kan bedenken waarbij we de grote maatschappelijk thema's die er leven kunnen tackelen door bouwkundige innovaties. En als je dat ook nog een geïntegreerd kan doen, meer dan bij BAM hoe ik dat heb beleefd is dan 1+1=3.
LD	MORALE/MOTIVATION	POS	intrinsieke motivatie om iets met hout te doen bij Lister Buildings terechtgekomen als stagiair
LD	MORALE/MOTIVATION	POS	Die hadden een geïntegreerde waardeketen en ik was daar zo door geïntegreerd ik dacht ja Dat is Dit is precies wat we nodig hebben in Nederland vanwege de schaarste In de markt maar ook de inefficiënties In de value chain. Dat vond ik heel vet, dat moet ik zelf ook gaan opzetten of zo
LD	MORALE/MOTIVATION	POS	. Die visie beviel me totaal niet, en je moet altijd vanaf het begin meenemen. Je kan niet als een soort randzaak zien, je moet het altijd centraal stellen. Dat is bij Lister wel aan de hand.
LA	MORALE/MOTIVATION	POS	. Maar Als het echt specifiek voor LA, het leuke is dat dat we gewoon Enthousiast, jonge gast zijn, zeg maar die allemaal. Het leuk vindt om hier aan te werken om het anders te doen. Echt geloven in wat in dat Lister verhaal, dat modulaire bouwen
LA	MORALE/MOTIVATION	POS	Ja dat, Dat is het mooie wat van wat we doen als als lister is. We ontwikkelen zelf iets leuk, hè? Je maakt een schetsje van op op meer massa niveau op oncept niveau. En vervolgens. Dat doe je eigenlijk gewoon met de kennis van hetgeen wat je aan de. Weet van het bouwsysteem en kun je dus snel een schets concreter maken naar iets wat wat wat ja, realistisch en en haalbaar is.
LA	MORALE/MOTIVATION	POS	Ook te de hele gedachtegang erop nahouden, zeg maar. Zo duurzaam mogelijk echt compleet duurzaam te bouwen. Dat je iets integraal oppakt en iets een stukje probeert op te lossen, maar dat je dat echt een breder vlak ben je het op te lossen.
LA	MORALE/MOTIVATION	POS	Alleen ik denk dat wij met het gebouw wta wij voor ogen hebben dat het allemaal kan, beter voor klimaat en beter voor mens. De ambitie is altijd al geweest om bio-based te bouwen, daar zetten we ook vol opin
LO	MORALE/MOTIVATION	POS	belangrijk voor mij om in een omgeving te werken waar ik het gevoel kon krijgen dat mijn werk een positieve bijdrage kon hebben in een betere omgeving en mens
LO	MORALE/MOTIVATION	POS	Wat mij vooral opviel was dat alles gewoon eenmalig gedaan wordt. In plaats van dat je bij een product iets ontwerpt wat meerdere malen geproduceerd wordt. Dus ik dacht daar is wel heel veel nog te doen als ontwerper, dus Ik heb dat vanaf het begin eigenlijk geprobeerd.om te kijken of er een andere efficiënte manier van bouwen is met geprefabriceerde elementen.
LO	MORALE/MOTIVATION	POS	Twee een heel juist nou die dat dat totale proces, want eigenlijk bij Lister proberen te vatten van ontwikkeling tot productie. Heb ik een hoge ambitie op duurzaamheid en circulariteit. Als je circulair wil bouwen, dan moet je beginnen en wel meer geld in stoppen, maar je kunt het alleen maar waar maken Als je ook het hele proces bestiert. En er zijn nodige drempels in te nemen.
LM	MORALE/MOTIVATION	POS	wat vind ik belangrijk: een team om iets op te bouwen en coachen haal ik veel energie uit. Las je het ook kan doen in een organisatie wat duurzaam is en goed voor de aardbol. Duurzaam is niet tekenend, maar organisatie Lister het product en de manier hoe we de keten inrichten en de motivatie is hoog. Als je waardeketen in eigen beheer heb kan je betere keuzes maken ook voor de toekomst.
LM	MORALE/MOTIVATION	POS	Wat is goud vind bij Lister is dat alles onder 1 dak is en je hebt een doel dus we kunnen betere keuzen maken
LM	MORALE/MOTIVATION	POS	En het concpet van Lister, modulair bouwen en duurzaam, bewust. Ja, dat sprak me heel erg aan om bij lister te werken.
LD	THRUST	POS	Je kent Iedereen al, je bent snel, zit je met elkaar aan tafel, dus de voorkant van het proces gaat veel sneller. Eigenlijk het hele door het hele proces gaat veel sneller Omdat je gewoon je collegas bent.
LD	THRUST	POS	Ik denk dat het niet als een belemmering voelt omdat het, naast dat het modulair is, is houtbouw momenteel heel hip en happening. Dus er komen klanten naar ons toe met de vraag van "kun je het eens bekijken met jullie systeem?" dus dat voelt nog niet als een belemmering, het voelt eerder als een kans.
LD	THRUST	POS	Erg prettig, want je weet precies van de personen en collega's als je wat vaker hebt samengewerkt wat je aan die persoon hebt: waar hij goed of slecht in is.
LA	THRUST	POS	Maar ik denk dat de manier waarop wij dat met lister doen, nu met ons bouwsysteem, dat dat een echt een hele goede invulling is. Het is er nog niet 100%, maar ik denk dat het wel In de goede richting is. Dus modulair op een op basis van Biobased materiaal, dus hout, losmaakbaar, remontabel (is een hele belangrijke), met een hoge standaard van kwaliteit.
LA	THRUST	POS	Dat is dus de grap. Je kunt wel zeggen als architect "nee, Ik wil meer vrijheid hebben, want dan kan ik dan kan ik meer in het ontwerp?" Maar dat wil niet perse zeggen dat je een beter gebouw krijgt.
LA	THRUST	POS	Het is echt een uitdaging dat wat we willen maken ook kunnen maken. Het is cool om te zien dat het ook lukt. Binnen mijn afdeling architecture: soms vergeet je dat je weken lang lijntjes aan het trekken bent, dan mis je soms even waarmee je bezig bent. Pas bij de presentaties heb je echt door dat je met iets anders bezig bent. Iedereen voelt dat ook wel!
LO	THRUST	POS	Mass Customization > Ik merk wel heel vaak dat het dat het ook niet helemaal bewust is en niet helemaal land.
LM	THRUST	POS	Binnen LM leeft dat, we staan met alle neuzen dezelfde kant op.
LA	THRUST	NEG	Da iedereen op de hoogte is dat wij bezig zijn met iets nieuws. Dus dat je niet kan verwachten dat dit project zoals een traditioneel proejct heel gemakkelijk VO in 6-8 weken een DO in 10-12 weken dat het er al staat.
LO	THRUST	NEG	Het was niet leuk omdat het veels te ambitieus was voor ene jong bedrijf. Ik vond het erg belastend om een iegen fabriek te hebben, omdat we tegelijkertijd 4 bedrijven aan het op zetten warenL vastgoedopntwikkeling, architecten team en een fabriek en het aan elkaar geschakeld bedrijf krijgen
LO	THRUST	NEG	Nee, we zijn met een lineaire werkwijze gestart. Probeer dat maar te gaan kantelen! Is er gehoor naar vernadering
LM	THRUST	neg	En ook bepaalde naiefiteit! Men denk heel snel dat het makkelijk is, terwijl het heel lastig is om sommige dingen te doen. Het zit mn voornamelijk in het bestuur
LA	THRUST	NEG	daar hebben we denk ik een paar fouten gemaakt door niet altijd met de belangrijkste dingen bezig te zijn.
LA	THRUST	NEG	We wilde teveel dingen tegelijkertijd waardoor we niet de focus hadden op de dingen die belangrijk zijn
LA	THRUST	ideal	eigenlijk heel gedegen en stapsgewijs een aantal ontwikkelingen doorzetten. Eerst wat is de strategie achter het systeem: wat moet het kunnen wat moet het niet kunnen. Ontwikkel het dan maar eens, ga eerst een PoC maken – een gedegen groeiplan, welke stappen doen we wanneer. Wij zijn gwn
LO	THRUST	POS	. We zijn zoveel met vernieuweing bezig: industraliasatie van de bouw, digitalisereinfg van de bouw, productmatig werken ipv project matig, materialen transitie.
LD	TOP MANAGEMENT COMMITMENT	POS	visie (aantrekkelijk bent als samenwerkingspartners)
LA	TOP MANAGEMENT COMMITMENT	POS	Nee je mertk dat Lister een beginnend bedrijf is waar iedereen met goede intensies het goed willen doen
LO	TOP MANAGEMENT COMMITMENT	POS	wat onze visie is voor de komende jaar: dat is denken en vooruit plannen,
LO	TOP MANAGEMENT COMMITMENT	NEG	Nee dat is ook lastig, het prbleem is dat de managemnt ook vanuit een lineare omgeving.

DEP.	CSF	OS/NI	Summary	Comment
LA	ADEQUATE EXPERIE	POS	Adequate experience and techn	Wat we doen is: We gaan kijken, wat zijn de dus als er al een plannetje dichtgaat checken van nou zijn de maat van het Van de gebouwtjes, een beetje conform hetgeen wat wij graag willen zien in ons bouwsysteem.
LA	ADEQUATE EXPERIE	POS	Adequate experience and techn	In mijn rol hebben we een systeem: aantal knopen waarin wij flexibel zijn en eigenlijk een opgave mee kunnen maken. Bijv. We doen een acquisitie, en een opgave met aantal woningen op een plot; en dat wij eensoort flexibiliteit hebbe
LO	ADEQUATE EXPERIE	POS	Adequate experience and techn	Ik heb 6-7 jaar voor CitizenM gewerkt, zij zijn ook modulaire bouwer. Ze zdoen traditioneel, modulair en renovatie.
LM	ADEQUATE EXPERIE	pos	Adequate experience and techn	. Ik heb daarvoor een hele geschiedenis als logistiek of supply chain manager binnen de maakindustrie, dit geval van hekwerken. Ja, Dat is allemaal productie gerelateerde activiteiten.
LM	ADEQUATE EXPERIE	POS	Adequate experience and techn	Ik heb hiervoor 4 jaar gewerkt bij Barli (Uden) ander bouwsysteem en andere markt, maar ook een andere mate van prefab woningen te maken maar niks gestandaardiseerd.
LO	ADEQUATE EXPERIE	POS	Adequate experience and techn	Nou ik hoop dat ik met mijn perspectief opleidng en evaring juist daarin andere input te geven en andere manier van denken kan geven. Architecten denken veel in fases, ik merk ook bij de digitalisering en het opzetten van het BIM mod
LO	ADEQUATE EXPERIE	pos	Adequate experience and techn	Ik ben industrieelontwerper van achtergrond, dus Dat is ook wel interessant in deze context. Begonnen als productontwerper en al lange tijd geleden, ben ik In de bouw eigenlijk verzeild geraakt.
LD	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Geld. En Mensen, OK, ja, geld en Mensen is het voornamelijkste ding. En investeringssteun ja investerings termijn. Dus Als je Als je tijd hebt, dan krijg je dat, krijg je die fabriek opgeschaald. Maar het is heel erg een economisch ding, tu
LD	ADEQUATE EXPERIE	NEG	Adequate experience and techn	missen we nog inkoopkracht
LD	ADEQUATE EXPERIE	NEG	Adequate experience and techn	o het bewustzijn zit hem, zit hem in ervaring.
LD	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Nou je kan natuurlijk op het moment dat ook de ontwikkelaar duidelijk weet wat de ontwerpprincipes en de realisatieprincipes zijn binnen zo'n project dan kun je dat veel efficienter maken
LD	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Alleen voor LM is het lastig want zij moeten voor het eerst een project doen, ze hebben nog geen trackrecord, dan kan je tegen onderaannemer zeggen haal er 10% af maar die zegt dan "wie ben jij dan?". Dat is niet helemaal representa
LA	ADEQUATE EXPERIE	NEG	Adequate experience and techn	maar door gebrek aan tijd en focus kmoen we daar niet aantoe. Het heeft ook echt te maken met een onderbezet team.
LO	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Ze kennen niet de meer agile contexten en de mogleijkheden daarvan. Maar ook de collega's, maar ook de jonge mensen, ik ben soms zo vertelt door het gebrek van kennis van mijn collegas bij LA van bijv BIM. Het blijft een raar ding. H
LO	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Het huidige engineering en manufacturing team is onder vertegenwoordeigd/ te weinig, en ze moeten systemen opzetten
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	- Het process wta ik net beschreef is goed voor een bedrijf waar 100 man werken en die hebben wij niet. Voordat je al die elementen heb uitgekristalliseerd hebt ben je al met een aantal mensen een jaar verder dan ben je te snel begonnen.
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Het overstappen naar een geindustrieerde omgeving wordt nu nog belemmerd door oude ervaringen uit de bouw.
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Er is wel een gemis dta ik niet in de bouw hebt gewerkt, want veel kennis neem je daarvan wel weer mee naar je volgende werk. Bij mijn vorige wekgever ging het over de iimplementatie van een onderdeel in een gebouw wat achteraf were
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Twee denk ik dat er bij LB heel veel uit de bouw ervaring, en weinig uit de product omgeving. Dat maakt niet makkelijk om in elkaars denkbeeld om dat te begrijpen, en ook niet omdat de bouw anders georganiseerd is
LO	ADEQUATE EXPERIE	neg	Adequate experience and techn	In feiten, het team wat daar zit hebben ze niet de core capaciteit die het kunnen doen. Jeroen heeft een goede ervaring in een manufacturing omgeving, bij HERAS, van 98%>99%. Nu moet hij van 0>40% de basis neerleggen en met ee
LO	ADEQUATE EXPERIE	IDEAL	Adequate experience and techn	: het heeft ook te maken met als je van startup naar scale up naar corporate wil gaan heb je een hele kleine cel van mensen die binnen die start ip werken en zij hebben allemaal meer expertise van meer aspecten. Er zijn gaten en die va
LO	ADEQUATE EXPERIE	NEG	Adequate experience and techn	manufacturing niet doen omdat ze bezig waren om de fouten van gisteren nog te herstellen.
LO	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Wat ik zie is dat het ene waar we als project de hele tijd tegenaanlopen is de installatie en de constructie. Daar zijn veel bottlenecks, tweededraagweg, veel dingen die verwove nmet elkaar zijn. Leveren zoveel beperkingen op! Ik zie da
LO	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Er is nog heel veel te verbeteren. Flow is nog ver te zoeken. Werkvoorbereiding loopt beetje achter, maar in mijn ogen wordt er veel te veel aan werkvoorbereiding gevraagd.
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Als je nog geen standaard product hebt kun je niet uitvogelen welke stap het langst duurt, want misschien komen we erachter dat we niet 20 maar 25 stations nodig hebben om ons product te maken. Dit weet je alleen maar door te doen
LM	ADEQUATE EXPERIE	NEG	Adequate experience and techn	Ja, en ook hier in de fabriek zijn we zijn nog altijd bezig met het met het opstarten in feite.
	ADEQUATE EXPERIE	POS	Maturity of techniques through re	Als je zet kijkt naar de productie, dan zouden we alles aan de voorkant dus LD LO en LA In het werk moeten stellen om nog meer te standaardiseren. Dan gaat daar de kostprijs omlaag, de productie omhoog en vervolgens dus de snelhe
LD	ADEQUATE EXPERIE	POS	Maturity of techniques through re	Nou wat je binnen Lister merkt is dat dat verandert hè. Eerst was niks te gek, en nu wordt er voorzichtig gekozen voor het standaard product waar dus mijn acquisitie vrijheid in beperkt wordt.
LA	ADEQUATE EXPERIE	pos	Maturity of techniques through re	Ja nee, en zeker in ons banksysteem maar voor woning heb je gewoon het liefste zo stramien maat van 3,5- 4 m. Ja jouw woonkamer wil je ook niet heel veel breder hebben dan 5 m bijvoorbeeld. En twee modules die naast elkaar staan c
LM	ADEQUATE EXPERIE	POS	Maturity of techniques through re	We hebben nu een verbeterlijst ontwikkeld, welke dingen komen we dagelijks tegen en zouden we iets mee moeten, dat gaat naar LO. Dat wordt gekoppeld aan dat verbeter proces.
LO	ADEQUATE EXPERIE	NEG	Maturity of techniques through re	met ProofOfConcept (paviljoen, milsbeek en koffiefabriek), is dat ze elkaar overlappen met fases. J
LO	ADEQUATE EXPERIE	NEG	Maturity of techniques through re	Wat we nu bij referentie gebouw doen wil je met de ontwikkeling maar ook met LM goed afgestemd hebben dat het goed in het systeem geborgt is.
LM	ADEQUATE EXPERIE	NEG	Maturity of techniques through re	. Ik denk dat daar ook gewoon een terugkoppeling moet of kan zijn in het belang van Liter in ieder geval onze belevingen met samenwerkingen en ervaringen en hoe het allemaal loopt dat, dat moeten we wel mee gaan nemen.
LD	ADEQUATE EXPERIE	NEG	Maturity of techniques through re	Nee, nou ja inhaalslag? Meer ervaren en senior je bent beter je dat kan, hoe makkelijker het project. Als je kijkt naar Paviljoen, Milsbeek en de koffiefabriek. We zijn net begonnen met een paar projecten. Ja, kun je dan verwachten dat h
LD	ADEQUATE EXPERIE	POS	Maturity of techniques through re	GAIN> proof of concept, we hebben het nu paar keer gedaan en weten hoe het moet
LA	ADEQUATE EXPERIE	POS	Maturity of techniques through re	Nou ik zie wel dat we project na project en fase na fase verbeteren. Het verschil tussen DO milsbeek en DO KF dat is echt wel dag en nacht verschil. Ik denk dat je dat nodig hebt om die stappen te maken
LA	ADEQUATE EXPERIE	pos	Maturity of techniques through re	De dingen die we wel kunnen schaven en wta we niet kunnen schaven dat we dat al vrloeg in het ontwerp process duidelijk hebben en ook niet meer opterug komen in een later stadium
LD	MODULAR PRODUCTIO	POS	Defined design & tech specificat	Nu al bij acquisities houden we rekening met standaard beukmaten op dit en halen we onze input op bij Hugues voor de systeem ontwikkelingen.
LD	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Hoe eerder je die zekerheid hebt hoe beter die ontwikkeling gaat. Als ik in SO al weet dat ik over twee jaar een product oplevert binnen planning en budget en dan wordt mijn werk heel makkelijk, hoef ik Alleen nog maar het omgevingsma
LA	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Dat hebbenw e aan de voorkant te weinig gedefineerd. Wat is nou de mate van felxibiliteit die wij onszelf kunnen bieden. Daar plukken we nu de zure vruchten van.
LA	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	. Eerst systeem ontwikkelen met het gebouw zelf en daaruit zijn een aantal voorwaardes gekomen en uitgangspunten en die zijn meegenomen naar KF, of er we blij mee zijn of niet .maar we moesten uitgangspunten hebben om door te k
LA	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Er zijn ene aantal fundamentele uitgangspunten waardoor het lastig is om verder te gaan.
LA	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Maar wat Lister op systeem niveau anders, wat zijn de fundamentele verschillen tussen projecten. Milsbeek wordt vergeleken met Paviljoen, en dat is lastig om met elkaar te vergelijken en de modules zijn anders. De eisen zijn anders, ke
LO	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Een van de groostte vercschillen tussen constrcution vs manufactuing proces, is dat manufacturing proces het helder oet zijn wat het product is. Daar zijn wij niet in staat geweest tot nu toe om het product te definieren. Wat is de modu
LM	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Het probleem bij Lister is dat er géén gestandaardiseerd product is. Dus we hebben wel een idee en een filosofie over het product,maar we hebben niet totachter te komma wat dat product is. Klopt en als ik praat over standaarden heb i
LM	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Hoe loopt dat op dit moment goed, maar het probleem izt hem in de werkvoorbereididng en de engineering want je hebt geen standaard product dus alles moet opnieuw uitgevonden worden.
LM	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Ja dat klopt we hebben nog geen product, niet in de keten samenwerkingen als in de techniek.
LD	MODULAR PRODUCTIO	NEG	Defined design & tech specificat	Extreem goede informatie en kennis over hoe nou de module gemaakt wordt > productie
LD	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	In mijn ideale wereld is het systeem al zo uit geëngineerd dat wij knooppunt in SO al alle details er al aanhangt en achter zit. Dat het al een uitontwikkeld detail is zodat je daarin dat de rest van het proces niet echt meer naar hoeft te kij
LD	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Ja of andersom. Want als je met name vanuit de LA of Lm(werkvoorbereiding) niet 100% goed ge-engineerd is heb je tijdens de assemblage in de fabriek of op locatie loopt het uit de pas. Dus dat is in het begin moet alles uit gekristallise
LO	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Ideaal gezien, iets wat we al helemaal uitge-engineerd moeten zijn. Dus je werkt met iets fijsn waarmee we gaan configureren. Dus daardoor komt dat proces op de schop, voor een deel!
LM	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Dus zij hebben wel veel informatie van LM het het product te kunnen verkopen mar daar is onduidelijkheid over. Geen vaste kostprijs. Dat is erg belangrijk, maar op dat punt zijn we nog niet.
LM	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Maar heeft meer te maken met waarmee me bezig zijn, de projecten die nu lopen zijn nog niet het standaard productie wat we willen. Daar zie ik we de zelfde kansen en bedreigingen. Je ziet weer dat we soms bij dingen goede focus moe
LM	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Eigenlijk wil je, bij een totaal gestandaardiseerd product, moet je eerst zorgen dat dit product boven deze projectstructuur helemaal klaar is. Dus dat is een aparte ontwikkeltak: R&D die die modules maakt (LO). Hughues moet zorgen da
LA	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Ja daar zouden wij heel goed geholpen door kunnen worden bijv vanuit de LO kant, als wij die bouw-blokjes aan de voorkant aangereikt krijgen, want dan hoeven wij ons alleen maar zorgen te maken over die 20% variatie.
LM	MODULAR PRODUCTIO	IDEAL	Defined design & tech specificat	Ik denk dat we een jaar moeten egineeren aan 12 standraard modules. Als je die hebt dan kan je gaan finetunen. Ik communiceer dit ook naar mn collegas maar het is lastig. We zitten nog niet in de modus van industrialiserende manier i
LA	MODULAR PRODUCTIO	ideal	Defined design & tech specificat	Als we nou gwn vanaf het begin bezig waren geweest met 3D goed uitnassen en goed overnadenken waarom we nou 3D werken, zodat er daardoor geen discussie meer is.

LD	MODULAR PRODUCTIOI	NEG	Early design freeze	Dat is wat er in het begin met Paviljoen ook gebeurde, oh ja, we willen dit en dit en dit ook nog anders. De design freeze zat halverwege je assemblage. Ja, dat kan niet, dat klopt.
LD	MODULAR PRODUCTIOI	IDEAL	Early design freeze	Als we echt die 1.0 versie vastleggen, maakt dta voor LD ook makkelijker van hiermee moeten we het doen en hiermee kunnen we aan de slag. Wet zitten in zon begin project, we moeten ook van LD weten wat willen jullie verkopen en wa
LA	MODULAR PRODUCTIOI	NEG	Early design freeze	Wij hebben uitgangspunten nodig hebben voor het ontwerp en we kun dus niet hele tijd als LD iets nieuws heeft dat weer invoeren in het ontwerp. Anders krijg je de hele tijd veranderingen in het onwerp, wat niet fijn is voor ons, maar oo
LA	MODULAR PRODUCTIOI	NEG	Early design freeze	Naast dat we dit technisch in elkaar proberen te zetten is er ook nog een maakbaarheid vraagstuk. We maken het ook naast het ontwerpen. Vroeg in de fases moeten we al nadenken of we het kunnen maken of niet, LM heeft daar natuu
LD	MODULAR PRODUCTIOI	POS	Scalability through standardizatic	Goed! Ik denk dat we een systeem hebben ontwikkeld wat goed maakbaar is, wat ook uitzonderingen aankan wat we hebben en tegelijkertijd is er puur vanuit de productie/assemblage perspectief meer behoefte aan verdere standaardis
LD	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	PAIN> hoe krijg je het opgeschaald en hoe kan je kosten efficiënter produceren. Dat heeft met de schaal te maken en daar zitten we nu precies in.
LA	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	Maar alsnog ben ik echt van overtuigd dat je met een set van 12 tot 6 verschillende woningplattegronden met de galerijen, een portiek of een corridor ontsluiting ook je een heel groot deel van de markt kan bedienen en daar kun je hele
LA	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	Wat we in het verleden gewoon niet goed gedaan hebben, is dat we heel veel projecten eigenlijk als one-offs/unique projects zijn aangevlogen. Wat ook logisch is, want we hadden eigenlijk nog geen systeem en nu hebben we steeds m
LA	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	En dat heeft er echt mee te maken dat we een jong bedrijf zijn, twee omdat er geen standaard product is.
LA	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	dat die drie verschillende systemen hebben drie verschillende organisaties achter zich staan. Dat gaat heel erg over het verschuiven van een focus van bouwen in een fabriek (3D) ten opzicht van onsite (2D) en dan heb je minder mens
LO	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	Ander probleem is de complexiteit van de projecten
LM	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	Moielijkheid nu zit in de diversiteit! Er zijn teveel ballen om hoog te houden, gelukkig door serge is het wat minder geworden. Hij pakt werkvoorbereiding over
LO	MODULAR PRODUCTIOI	NEG	Scalability through standardizatic	Als ik onderscheidend wil zijn moet ik nieuwe blokjes hebben. En dat is wat je verder ontwikkeld in de andere phsaes.
LD	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Wij als LD willen ontwerpvrijheid en de bouwer wil dat niet. Daartussenin is ergens een sweetspot en die vinden, dat is wel een uitdaging. Daar heb je dan ook bepaalde acquisitiestrategie nodig die niet teveel afwijkt.
LD	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Je wil dat er bepaalde mate van customize-ability wordt toegevoegd, daar heb je dus weer een aparte productielijn voor. Bijvoorbeeld met auto's.
LA	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Wat je in de fabriek wil is zoveel mogelijk standardisatie om zo makkelijk mogelijk proces in te voeren
LO	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Dus je bouwt 80% standaard en de rest focus je op de onbekende delen die je wellicht wel in ene gefaseerde ontwikkeling kan hebben maar die zullen korter zijn.
LO	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Toen ben ik bij een architect gaan werken, die had ook een concept wat herhaalbaar of herhaaldelijk werd gebruikt.Daar konden architecten verschillende ontwerpen uploaden en aandragen en die werden dan weer hergebruikt, meer e
LO	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Mass custimzation is misschien wel helemaal de oplossing, zeg maar, dan kunnen die standaardisatie eigenlijk helemaal overslaan bij wijze van spreken maar je houdt wel dat je nog steeds veel engineering hebt dan. Want je moet wel c
LM	MODULAR PRODUCTIOI	IDEAL	Scalability through standardizatic	Op basis van het standaard product kan je ook gaan configureren, op het moment dat je configuratie bekend is dan heb je je gebouw dan moet je je schil nog bepalen maar je weet iig dat je al kan gaan produceren.
LD	MODULAR PRODUCTIOI	ideal	Scalability through standardizatic	• voor Lister is dat niet goed om te veel te standaardiseren > je wil die keuzevrijheid wat je zegt verschillende ding kunnen maken, zowel module als woning als gebouwniveau, maar puur voor het productieproces los van de afzetmarkt, z
LD	MODULAR PRODUCTIOI	ideal	Scalability through standardizatic	Dat je eerst limiteren, en daarna weer uitbreiden en dat je met eenzelfde ontwikkelproces 1000x producten kan maken omdat je gestandaardiseerde schroefjes en boutjes etc.

Department	CSF	POS/NEG	Summary	Comment
LD	**Management**	IDEAL	Coordination between interfaces	Het hele ontwikkelproces is de ontwikkelaar de leiding nemen. Maar als je uiteindelijk naar het systeem denken benadert dan zou er een veel grotere rol zijn voor de systeem architect of LS.
LA	**Management**	IDEAL	Coordination between interfaces	Hier komen LD en LM naast elkaar staan, want LD wil misschien een grotere woning maar LM kan zegen ho dat gaat niet. De balans gaat steeds meer naar de fabriek. Maar LA heeft de leiding, maar wij zitten niet op de stoel van de fabrie
LD	**Management**	NEG	Coordination between interfaces	Eigenlijk vult de LA op dit moment het belangrijkste intermediair tussen. In het ontwerpproces tussen LD en LM.
LD	**Management**	NEG	Coordination between interfaces	Er is namelijk een moment van overdragen dat er een gat valt.
LD	**Management**	NEG	Coordination between interfaces	Klassiek gezien heeft de LD altijd de regie, dat kan LO LA EN LM niet. De invloed van de ontwikkelaar heeft altijd de grootste invloed, en de andere gaan specifiek over een onderdeel van de ontwikkeling. Als ontwikkelaar ben je bezig m
LD	**Management**	NEG	Coordination between interfaces	Je moet meer bewustzijn daarvan creëren en goed voorzitterschap.
LD	**Management**	NEG	Coordination between interfaces	Als Lister development de grootste rol speelt in deze phases, hoe houden zij het belang erbij, dat het project succesvol verloopt: Ja LD zijn de regisseurs he, iedereen triggers om tot een oplossing te komen die binnen budget past, binr
LD	**Management**	POS	Coordination between interfaces	Natuurlijk is het in ons geval een Four Way Street. Er moet wel gecoördineerd worden van dat proces en het Voorzitter ligt altijd bij de projectverantwoordelijke en de dat is altijd de development manager of de projectmanager ja
LD	**Management**	POS	Coordination between interfaces	o Normaal gesproken zou ik in principe zeggen overal is development in principe verantwoordelijk voor project alleen onze invloed neemt af. Dus [laat tekening zien van down curve] zo ja dus als dan dus dan zou dit een zijn.
LO	**Management**	POS	Coordination between interfaces	Mijn taak was eigenlijk om de afdeling, development, architecture, systeemontwikkeling en manufacturing met elkaar te verbinden, zeg maar ja, na elkaar beter te Laten samenwerken, te begrijpen.
LM	**Management**	POS	Coordination between interfaces	Ja hoe wij het produceren is een resultaat van de samenwerking.
LM	**Management**	POS	Coordination between interfaces	We hebben een planningsprogramma wat in de pijplijn ligt om geinstalleerd te worden , wat voeten in de aarde heeft. Algemeen moeten we daar nog echt stappen in maken om alles aan elkaar te sluiten.
LD	**Management**	POS	Coordination between interfaces	Die is altijd eindbeslissing, dus de dus. Maar wat je ziet is dat is klassiek en klassiek werkt de ontwikkelaar Samen met de bouwer. De bouwer is uiteindelijk neemt de ontwerp verantwoordelijkheid over en moet het gaan maken, omdat hij
LD	**Management**	IDEAL	Coordination between interfaces	Ja kan, maar als je kijkt op modules niveau heeft de ontwikkelaar minder invloed op het proces, maar op gebouw niveau is dat wel zeker de ontwikkelaar. In principe wil je dat de ontwikkelaar zo snel mogelijk niks meer hoeft te zeggen ov
LO	**Management**	NEG	Coordination between interfaces	Het is belangrijk dat je een bepaalde systemeatiek en ordening in die lijst krijg.t Je krijgt een hele lange lijst, beetje dode lijst, dus je moet kijken hoe je dit prioriteert en wie dan de leiding daarvan neemt. Ik ben nu een standaard opmaak
LA	**Management**	POS	Coordination between interfaces	Nee LD is nog steeds betrokkken, LD is onze opdrachtgever, zij zijn degene die de grote beslissingen moeten maken in het ontwerp, als er aanpassingen zijn vanuit ons of zij hebben technische PvE waar wij aan moeten houden. Het is e
LD	**Management**	NEG	Early planning and scheduling	Nou tijdens de realisatie van het paviljoen is de werkvoorbereiding gelijktijdig gestart met de assemblage. Ja, dan weet je eigenlijk al bij voorbaat gaat hem niet worden. Nou ja, dat zat dus In de tijd, dat was helemaal verkeerd gepland. \
LA	**Management**	POS	Early planning and scheduling	Sinds Serge rondloopt komt er een bepaalde structuur aan de voorkant: planning en aansturing en inhoudelijke kennis.
LA	**Management**	IDEAL	link between design and product	Dat gat tussen de twee locaties en dedicated is om input te leveren, of hij of zij input ophalen die het weet. Dat daar veel meer draagkracht in krijgt
LO	**Management**	IDEAL	link between design and product	Ik denk dat de maakbaarheid en de logistiek hoe we die dingen prodcueren veel meer naar voren moeten trekken. Dat is LM, maar wij als LO een rol in kunnen spelen om te voelen. Waar wij wel een hele grote rol in kunnen spelen is, en h
LO	**Management**	IDEAL	link between design and product	. Je hebt iemand nodig die de informatie upstream naar downstream. We hebben een ober nodig. De enige die er nu is is Wesley, maar met dit project heb je 5 wesleys nodig (understaffed).
LM	**Management**	IDEAL	link between design and product	Wat je daaruit kan zeggen is dat de engineering moeten toevoegen om het product te ontwikkelen als we dat hebben kunnen we met opschalen automatizeren en in de tussentijd zou je langzaam met mensen kunnen opschalen: transpo
LM	**Management**	IDEAL	link between design and product	Wel nog interessant, ik zelf denk dat binnen LM ene productontwikkelaar moeten hebben, die zou de module moeten maken zoals de lego blokjes die we kunnen maken en samen met LO de ontwikkeling over het gebouw gaan bekijken. I
LA	**Management**	neg	link between design and product	Hoe ik het nu zie is het met name, bespreken we wekenlijks in het team, hoe je verbinding maakt met de fabriek. Hoe de informatie die daar speelt verwerkt in ons ontwerp, maar andersom ook, hoe ons ontwerp daar goed land.
LD	**Management**	NEG	link between design and product	Nou, toen hadden we geen projectleider vanuit mijn manufacturing, geen projectcoördinator, geen echte uitvoerder. Dat had je eigenlijk allemaal niet, terwijl je die wel wil hebben vanaf het begin. Ja, want dat zijn de communicatie punt
LD	**Management**	NEG	link between design and product	Dan de projectleider vanuit de technische kant vanuit de aannemer die snel in het project moet betrekken en die op een gegeven moment ook kan beoordelen. Van oké, weet je, We zijn ver genoeg hier, freezen we gaan produceren en
LA	**Management**	NEG	link between design and product	Alleen met LM merk ik echt dat in de werkvoorbereiding dat er een kloof is met wat wij hier verzinnen en wat wij in de fabriek plaatsvindt.
LA	**Management**	NEG	link between design and product	Ik zie het als ene gebouw met 3 gallerijen ertussen met berging, zij zien dit als 100 verschillende elementen met verschillende nummers. Dus dat vershcil hoe je naar een project kijkt is enorm aanwezig.
LA	**Management**	NEG	link between design and product	En dan komt het bij onderdragen TO, "joh perfect we hebben de tekening" maar paar weken later komen ze erop terug. Dat komt gwn omdat er NIEMAND bij LM DEDIDATED is om bij SO al aan tafel te schuiven. Het komt er nu op neer, ze
LO	**Management**	NEG	link between design and product	Eigelijk is architecture ook de schakel waar manufacturing afhankelijk was. Het was een treintje: als dev hun werk goed doet dan zal er minder werk zijn voor arch en als arch werk goed doet is er minder werk voor manuf. Maar ja ik kwam
LO	**Management**	NEG	link between design and product	. Ik heb het gevoel gehad dat ik dacht dat ik dingen niet hoefde te zeggen omdat ze voor mij logisch waren, omdat ik de erbanden kende uit mijn praktijk ervaring. Maar ik merkte dat ik sommige stappen viseul en duidelijk maken, van als
LO	**Management**	NEG	link between design and product	Ik mis de projectmanager, die tussen het bedenken zit en het maken.
LO	**Management**	NEG	link between design and product	Ja, maar dat gebeurt nu ook en meer. LA probeert het wel om LM te voeden en te sturen alleen dat loopt nog moeizaam. De een zegt we worden niet betrokkken en de ander zegt we krijgen geen contact. Ze gooien de bal naar elkaar toe
LM	**Management**	NEG	link between design and product	*Wat missen we op ditmoment het meest?* Engineerings, installatie engineers en bouwkundige engineers. De translatie tussen de tekeneingen en de werkvloer.
LM	**Management**	NEG	link between design and product	Tussen weert en den bosch is er volgens mij overgedacht om een functie hiertussen moest komen. Serge is realitie en voorebereiding maar dat is voor in Weert,maar er is geen overkoepelde functie tussen DB en Weert. Nu zie ik daar ge
LM	**Management**	NEG	link between design and product	. Maar als we dat hier krijgen moeten we elke unit opnieuw engineren en het ontwerp uit elkaar halen om het hier maakbaar te krijgen. Elke keer moet er een revit tekening uitgeplozen.

LD	Organization	IDEAL	Effective alignment on responsib	Ik denk dat LO werkt aan een systeem wat LM moet maken, en LA ontwerpt aan het product wat LM maakt. Dus list de LA en LM zijn de regisseurs tussen wat je vanuit een ontwikkelperspectief op projectniveau wil en hoe je in dat projec
LA	Organization	IDEAL	Effective alignment on responsib	Als ontwikkelaar wil je gewoon een mooie gebouw realiseren met een mooie rendement om het zo maar te zeggen. Als architect, ben je mee bezig van wat welke kwaliteit is dit gebouw dadelijk en blijft het Misschien wel 100 jaar staan? W
LM	Organization	IDEAL	Effective alignment on responsib	*Zou je zeggen dat LM in SO fase een meer adviserende rol heeft?* Ja met LO, ja. Binnen LM moeten de producten maken en LO is bezig met het verbeteren. Ik denk dat je verbeterslagen kan halen met degene die het gaat maken.
LD	Organization	IDEAL	Effective alignment on responsib	Ja kan, maar als je kijkt op modules niveau heeft de ontwikkelaar minder invloed op het proces, maar op gebouw niveau is dat wel zeker de ontwikkelaar. In principe wil je dat de ontwikkelaar zo snel mogelijk niks meer hoeft te zeggen ov
LD	Organization	NEG	Effective alignment on responsib	"Ah dit is zo lastig" In mijn hoofd zitten Lister Architecture en Lister Systeemontwikkeling nog een beetje aan elkaar vast.
LD	Organization	NEG	Effective alignment on responsib	Ik vind die LO en LA lastig! In mijn optiek is dat soort van aan elkaar geplakt.
LD	Organization	NEG	Effective alignment on responsib	Ja met collega's die misschien opeens hele andere rollen moesten gaan aannemen ten opzichte van waar ze eigenlijk goed in zijn.
LA	Organization	NEG	Effective alignment on responsib	daar moeten we echt met LM een gesprek moeten voeren over TO.
LO	Organization	NEG	Effective alignment on responsib	LA heeft een presentatiemodel en dat wordt dan een digitaal productiemodel omgezet worden maar hoe het nu gaat wordt het ook opnieuw getekend maar dat hoort niet, er moet gwn op voort kunnen voortduren en dat dan omzetten na
LM	Organization	NEG	Effective alignment on responsib	Wat ik nog niet goed vind gaan is dat we met elkaar het gezamenlijke belang niet uithoren. Dan wordt er iets ontworpen en dan komt dat hierin Weert te liggen en dan gaan we dat maken en dat kunnen we niet maken, dan wordt er gevloe
LD	Organization	NEG	Effective alignment on responsib	Ja, dus op het op het moment dat je een project opstart, gaat het al vrij snel over het productieproces, en hoe project daar dan goed bijpast. Dus het heeft een behoorlijke invloed. Het is ook vrij snel onderwerp van gesprek, te snel in m
LA	Organization	NEG	Effective alignment on responsib	NEG: de lastigheid eraan is ik snap ook dat ieder bedrijf in elke vastgoedketen zijn eigen specialisme heeft. Omdat je daarmee je specialisme kan ontwikkelen en wij zijn tegelijkhertijd op al die verschillende terreinen en dan heb ik het b
LD	Organization	POS	Effective alignment on responsib	Lister Development: de reden dat wij acquisities doen is omdat LM een behoefte heeft. Als LM niks doet dan doet LD ook niks
LA	Organization	POS	Effective alignment on responsib	We hebben ook een set gemaakt van wat wij als LA per fase moeten wij leveren/output.
LA	Organization	POS	Effective alignment on responsib	*Ik heb LA en LO apart genomen.* Ja heel goed.
LA	Organization	POS	Effective alignment on responsib	Normaal gesproken is die lijn heel erg strikt, LM moeten terug naar LA of LD als veranderingen in het ontwerp komen, omdat zij er normaal gesproken niks van moeten vinden. Maar Nick is ook architect voor dit project t ook op! Dus hij zie
LA	Organization	POS	Effective alignment on responsib	Eigenlijk heeft LO geen invloed op het project, dus zij staan volledig buiten het project. Als wij aan een project beginnen pakken wij de laatste innovatie van de module en gaan daarmee aan de slag.
LO	Organization	POS	Effective alignment on responsib	LA kan er heel goed over nadenken maar zij hebben ook behoefte aan die input. Dat is een andere manier van ontwerpoplossen. Anders nadenken over de oplossing.
LM	Organization	POS	Effective alignment on responsib	Hier is het LD en die moet goed samen kijken bij LO wat ze denken te gaan te verkopen. LA kijkt of het past in het geheel en wij als LM volgen wat zij erover zeggen.
LM	Organization	POS	Effective alignment on responsib	Ik vindt dat systeem ontwikkeling ten alle tijden het belangrijkste is van het project. Want anders ga je nooit de module optimaliseren
LM	Organization	POS	Effective alignment on responsib	. Wij als Lm krijgen door LA het ontwerp aangeleverd, en wat is afgestemd met LD en verbeterd door LO en geproduceerd door LM
LM	Organization	IDEAL	Effective alignment on responsib	Het is ook vaak kolom gestuurd. De bedrijven bestaan uit meerder discipline s , waarin elke discipline zijn eigen takenpakket had en zijn taakje overdraagd naar een andere discipline en dat dan weer in een productie keten kan dat snel
LM	Organization	IDEAL	Effective alignment on responsib	Je had een partij R&D, en die haalt bij marketing informaie over wat iets in de markt zou kunnen doen. Je gaat ermee aan de gang en die bedenken iets en die gaan testen en kijken of het zou passen, bedenken een productieproces erb
LM	Organization	IDEAL	Effective alignment on responsib	Als je LM vergelijkt met een autofabriek kun je configureern op het internet en krijg je precies hoeje hem wil en komt er een levertijd en een kostenplaatje bij, daar komt de dealer niet bij kijken. Dus het hele tussenliggende traject is dan
LD	Organization	NEG	Effective alignment on responsib	Ook door de geïntegreerde keten. Dat is LM een beetje aan LO en LA hangt dus daarom is een beetje twijfel van: Hoe vul je dat in en dan? Dan is daarom is op dit moment de intensiteit met Lister Architecture groter, terwijl die Misschien
LM	Organization	IDEAL	Change in development process	Je wil veel meer naar een ETO of een MTO product, dat kan in een bepaald gedeelte van het gebouw. Ik denk wel dat dat besef er in heel de keten wel is, het enige wat wel interessant zou zijn is dat je zou moeten kijken waarom we dit do
LD	Organization	IDEAL	Change in development process	Dat je eindelijk van SO of VO, meteen naar TO kunnen. Dat je DO overslaat. Of dat je het ontwikkelfase verkort. Het aq fase is zacht ook in het klantencontact en dat kan zomaar heel lang of snel duren en daar heb je geen invloed op.
LO	Organization	IDEAL	Change in development process	Als je een uitontwikkeld product heb: die je tot realisatie heb doorgrond, beproefd en getest en van varianten voorziet die zet je alvast in je voorlopig ontwerp. Dus dan zou je een kort SO hebben en een vrij lang VO en bijna geen DO en
LO	Organization	IDEAL	Change in development process	DE VRAAG IS is dat nodig binnen een product ontwerp traject. Misschien heb je maar twee fases nodig? Hadden we vorige week nog over, ik zie dat we moeten heroverwegen om een logische aanpak te geneneren voor ons prodycr. Al c
LM	Organization	IDEAL	Change in development process	Als je het voorwerk uitgekristalliseerd dan betekend dat dat je alles wat erna komt qua ontwikkeling niet meer nodig hebt, geen VO DO of TO, misschien een DO, maar alle techniek zit er in principe al in.
LM	Organization	IDEAL	Change in development process	Als LO een dusdanig module product heeft wat uitgekauwd is, dan kan je tot VO alles in elkaar sleutelen en heb je bijna geen DO of TO nodig om te produceren.
LD	Organization	IDEAL	Change in development process	En dit proces dat je dat van een SO voorlopig ontwerp en DO naar een TO gaat, misschien zou je TO moeten aanpassen naar. Een andere term de techniek. Al eerder komt.
LD	Organization	IDEAL	Change in development process	De ontwikkelfase daar heb je heel veel invloed op als bedrijf, als je die nou kan indrukken dat zou ideaal zijn!
LO	Organization	IDEAL	Change in development process	Dat is nu niet zo. We zijn eigenlijk erg traditioneel bezig: eerst een adviseur, en dan komt LA erbij komt er iets uit en dan wordt LM erbij gehaald met dit willen we maken.
LD	Organization	POS	Change in development process	Kijk, In de basis hebben we de flowchart ook met Dirk Jan Maas, zeg maar, maar daar moeten we niet te zwaar aan, want dat is in ontwikkeling en dit is al de vierde flowchart die we hebben gehad, Er is niet one way. Ik denk dat het traditi

APPENDIX F - Results Production Profiles

		Lister Development									Lister Achitecture								
		#1			#2			#3			#1			#2			#3		
		LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△
Organization	Driver	-2	0	2	0	2	2	2	2	0	-2	2	4	0	2	2	-1	0	1
	Innovation	0	-1	1	-2	0	2	-1	1	2	-2	0	2	-1	2	3	-1	1	2
	Focus perspective	-1	-1	1	0	0	0	-1	0	1	-1	0	1	1	0	1	0	0	0
	Internal team set-up	1	-1	2	1	2	1	1	-1	2	0	2	2	1	2	1	1	1	0
	Organisation set-up	0	-1	2	1	2	1	-1	1	2	-1	2	3	0	1	1	0	-1	1
Product	Design Type	-1	-1	2	-2	0	2	-2	2	4	-1	0	1	-1	2	3	0	2	2
	Client input	1	-1	0	0	0	0	-1	0	1	-1	1	2	-1	1	2	0	0	0
	Design variety	0	-1	0	0	0	0	-1	-1	0	0	1	1	0	-1	1	0	-1	1
	Product configuration	-1	-1	3	-2	2	4	0	1	1	-1	2	3	1	2	1	-1	2	3
	Profit margin	2	-1	3	2	-1	3	2	1	1	2	-1	3	2	-2	4	1	-2	3
Production	Production rate	-2	-1	1	-2	2	4	-2	2	4	-1	1	2	-1	2	3	-2	1	3
	Production type	1	-1	2	-1	2	3	0	1	1	-1	1	2	1	2	1	0	2	2
	Supply chain	1	-1	2	-1	1	2	-1	2	3	-1	1	2	1	2	1	0	2	2
	Delivery time	-1	-1	0	0	2	2	-1	2	3	-2	0	2	0	2	2	-1	1	2
	Strategy	1	-1	2	-1	2	3	-1	1	2	0	1	1	0	1	1	0	0	0
	External relations	1	-1	2	2	2	0	-1	1	2	1	2	1	-1	2	3	0	1	1

		Lister Systeemontwikkeling						Lister Manufacturing								
		#1			#2			#1			#2			#3		
		LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△	LB1	LB2	△
Organization	Driver	-1	0	1	0	-1	1	0	0	0	-1	0	1	-1	1	2
	Innovation	-2	2	4	1	-2	3	0	2	2	-1	2	3	0	2	2
	Focus perspective	-1	0	1	-1	0	1	-2	0	2	-1	1	2	-2	1	3
	Internal team set-up	-1	2	3	2	2	0	0	2	2	0	2	2	1	2	1
	Organisation set-up	-1	1	2	-1	2	3	-2	2	4	-1	1	2	1	2	1
Product	Design Type	-2	-1	1	-1	1	2	-2	1	3	-1	1	2	-1	2	3
	Client input	-2	-1	1	-1	-1	0	0	0	0	0	1	1	1	1	0
	Design variety	-1	-1	0	1	1	0	-2	2	4	-1	1	2	-1	0	1
	Product configuration	-1	2	3	-1	2	3	-2	2	4	-1	1	2	-1	2	3
	Profit margin	-1	1	2	-1	-1	0	0	-2	2	2	-2	4	2	0	2
Production	Production rate	-2	1	3	-1	2	3	-2	2	4	-2	2	4	-1	2	3
	Production type	-1	1	2	-1	2	3	-2	1	3	-1	1	2	1	2	1
	Supply chain	-2	1	3	0	2	2	-1	2	3	0	2	2	1	2	1
	Delivery time	-2	1	3	0	2	2	-2	2	4	-1	2	3	0	2	2
	Strategy	-1	0	1	1	0	1	2	2	0	0	2	2	0	2	2
	External relations	-1	2	3	1	2	1	0	2	2	0	2	2	1	2	1

	DIFFERENCES LB1>	LB1	LB2	△	△T
Organization	Driver	-0,5	0,7	1,273	16
	Innovation	-0,8	0,8	1,636	26
	Focus perspective	-0,8	0,2	1	13
	Internal team set-up	0,6	1,4	0,727	16
	Organisation set-up	-0,5	1,4	1,818	22
Product	**Design Type**	-1,3	1,0	2,273	25
	Client input	-0,4	0,3	0,636	7
	Design variety	-0,5	0,1	0,545	10
	Product configurati	-0,9	1,8	2,727	30
	Profit margin	1,2	-0,6	1,818	27
Production	**Production rate**	-1,6	1,7	3,364	34
	Production type	-0,4	1,5	1,818	22
	Supply chain	-0,3	1,7	2	23
	Delivery time	-0,9	1,6	2,545	25
	Strategy	0,1	1,0	0,909	15
	External relations	0,3	1,8	1,545	18

Lister Buildings at present

		#1	#2	#3	#1	#2	#3	#1	#2	#1	#2	#3	
		LB1	LB1	LB1	LB1	LB1	LB1	LB1	LB1	LB1	LB1	LB1	
Organization	Driver	-2	0	2	-2	0	-1	-1	0	0	-1	-1	-0,5
	Innovation	0	-2	-1	-2	-1	-1	-2	1	0	-1	0	-0,8
	Focus perspective	-1	0	-1	-1	1	0	-1	-1	-2	-1	-2	-0,8
	Internal team set-up	1	1	1	0	1	1	-1	2	0	0	1	0,6
	Organisation set-up	0	1	-1	-1	0	0	-1	-1	-2	-1	1	-0,5
Product	Design Type	-1	-2	-2	-1	-1	0	-2	-1	-2	-1	-1	-1,3
	Client input	1	0	-1	-1	-1	0	-2	-1	0	0	1	-0,4
	Design variety	0	0	-1	0	0	0	-1	1	-2	-1	-1	-0,5
	Product configuration	-1	-2	0	-1	1	-1	-1	-1	-2	-1	-1	-0,9
	Profit margin	2	2	2	2	2	1	-1	-1	0	2	2	1,2
Production	Production rate	-2	-2	-2	-1	-1	-2	-2	-1	-2	-2	-1	-1,6
	Production type	1	-1	0	-1	1	0	-1	-1	-2	-1	1	-0,4
	Supply chain	1	-1	-1	-1	1	0	-2	0	-1	0	1	-0,3
	Delivery time	-1	0	-1	-2	0	-1	-2	0	-2	-1	0	-0,9
	Strategy	1	-1	-1	0	0	0	-1	1	2	0	0	0,1
	External relations	1	2	-1	1	-1	0	-1	1	0	0	1	0,3
		0	0	-1	-1	0	0	-1	0	-1	-1	0	

LD	0	LA	0	LO	-1	LM	-1

Lister Buildings in future

		#1	#2	#3	#1	#2	#3	#1	#2	#1	#2	#3	
		LB2	LB2	LB2	LB2	LB2	LB2	LB2	LB2	LB2	LB2	LB2	
Organization	Driver	0	2	2	2	2	0	0	-1	0	0	1	0,7
	Innovation	-1	0	1	0	2	1	2	-2	2	2	2	0,8
	Focus perspective	0	0	0	0	0	0	0	0	0	1	1	0,2
	Internal team set-up	-1	2	-1	2	2	1	2	2	2	2	2	1,4
	Organisation set-up	2	2	1	2	1	-1	1	2	2	1	2	1,4
Product	Design Type	1	0	2	0	2	2	-1	1	1	1	2	1,0
	Client input	1	0	0	1	1	0	-1	-1	0	1	1	0,3
	Design variety	0	0	-1	1	-1	-1	-1	1	2	1	0	0,1
	Product configuration	2	2	1	2	2	2	2	2	2	1	2	1,8
	Profit margin	2	-1	1	-1	-2	-2	1	-1	-2	-2	0	-0,6
Production	Production rate	2	2	2	1	2	1	1	2	2	2	2	1,7
	Production type	1	2	1	1	2	2	1	2	1	1	2	1,5
	Supply chain	2	1	2	1	2	2	1	2	2	2	2	1,7
	Delivery time	2	2	2	0	2	1	1	2	2	2	2	1,6
	Strategy	0	2	1	1	1	0	0	0	2	2	2	1,0
	External relations	2	2	1	2	2	1	2	2	2	2	2	1,8
		1	1	1	1	1	1	1	1	1	1	2	

LD	1	LA	1	LO	1	LM	1

- **Department profiles: Identifying Shifts**

Lister Development [LD]

		#1	#2	#3	#1	#2	#3	#1	#2	#3
		LB1	LB1	LB1	LB2	LB2	LB2	△	△	△
Organization	Driver	-2	0	2	0	2	2	2	2	0
	Innovation	0	-2	-1	-1	0	1	-1	2	2
	Focus perspective	-1	0	-1	0	0	0	1	0	1
	Internal team set-up	1	1	1	-1	2	-1	-2	1	-2
	Organisation set-up	0	1	-1	2	2	1	2	1	2
Product	Design Type	-1	-2	-2	1	0	2	2	2	4
	Client input	1	0	-1	1	0	0	0	0	1
	Design variety	0	0	-1	0	0	-1	0	0	0
	Product configuration	-1	-2	0	2	2	1	3	4	1
	Profit margin	2	2	2	2	-1	1	0	-3	-1
Production	Production rate	-2	-2	-2	2	2	2	4	4	4
	Production type	1	-1	0	1	2	1	0	3	1
	Supply chain	1	-1	-1	2	1	2	1	2	3
	Delivery time	-1	0	-1	2	2	2	3	2	3
	Strategy	1	-1	-1	0	2	1	-1	3	2
	External relations	1	2	-1	2	2	1	1	0	2
		0,0	-0,3	-0,5	1,0	1,1	1,0	0,9	1,4	1,4

LD	0

LD	1

Lister Architecture [LA]

		#1	#2	#3	#1	#2	#3	#1	#2	#3
		LB1	LB1	LB1	LB2	LB2	LB2	△	△	△
Organization	Driver	-2	0	-1	2	2	0	4	2	1
	Innovation	-2	-1	-1	0	2	1	2	3	2
	Focus perspective	-1	1	0	0	0	0	1	-1	0
	Internal team set-up	0	1	1	2	2	1	2	1	0
	Organisation set-up	-1	0	0	2	1	-1	3	1	-1
Product	Design Type	-1	-1	0	0	2	2	1	3	2
	Client input	-1	-1	0	1	1	0	2	2	0
	Design variety	0	0	0	1	-1	-1	1	-1	-1
	Product configuration	-1	1	-1	2	2	2	3	1	3
	Profit margin	2	2	1	-1	-2	-2	-3	-4	-3
Production	Production rate	-1	-1	-2	1	2	1	2	3	3
	Production type	-1	1	0	1	2	2	2	1	2
	Supply chain	-1	1	0	1	2	2	2	1	2
	Delivery time	-2	0	-1	0	2	1	2	2	2
	Strategy	0	0	0	1	1	0	1	1	0
	External relations	1	-1	0	2	2	1	1	3	1
		0,0	-0,3	-0,5	1,0	1,1	1,0	1,6	1,1	0,8

LA	0

LA	1

Lister System Engineering [LO]

		#1	#2	#1	#2	#1	#2
		LB1	LB1	LB2	LB2	△	△
Organization	Driver	-1	0	0	-1	1	-1
	Innovation	-2	1	2	-2	4	-3
	Focus perspective	-1	-1	0	0	1	1
	Internal team set-up	-1	2	2	2	3	0
	Organisation set-up	-1	-1	1	2	2	3
Product	Design Type	-2	-1	-1	1	1	2
	Client input	-2	-1	-1	-1	1	0
	Design variety	-1	1	-1	1	0	0
	Product configuration	-1	-1	2	2	3	3
	Profit margin	-1	-1	1	-1	2	0
Production	Production rate	-2	-1	1	2	3	3
	Production type	-1	-1	1	2	2	3
	Supply chain	-2	0	1	2	3	2
	Delivery time	-2	0	1	2	3	2
	Strategy	-1	1	0	0	1	-1
	External relations	-1	1	2	2	3	1
		0,0	-0,3	1,0	1,1	2,1	0,9

LO 0 LO 1

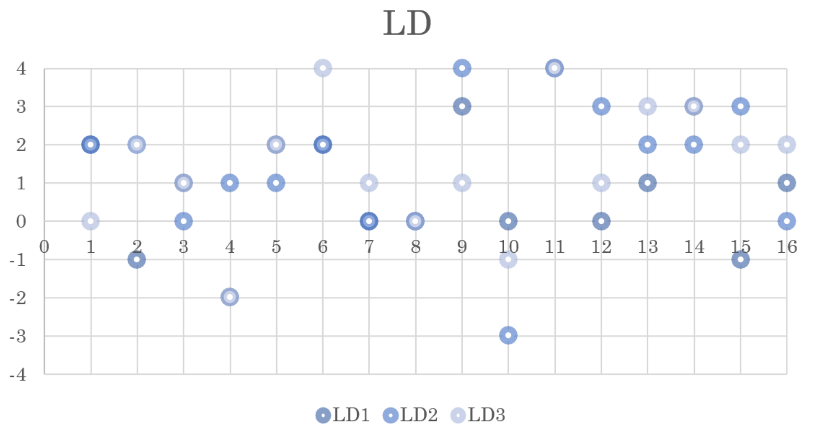
Lister Manufacturing [LM]

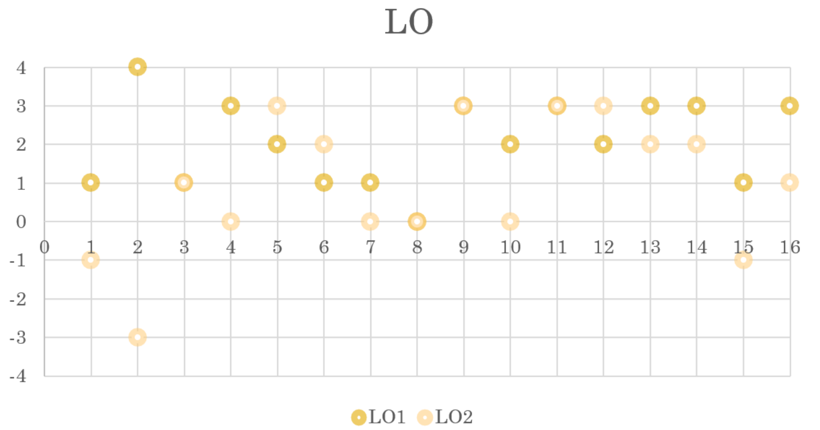
		#1	#2	#3	#1	#2	#3	#1	#2	#3
		LB1	LB1	LB1	LB2	LB2	LB2	△	△	△
Organization	Driver	0	-1	-1	0	0	1	0	1	2
	Innovation	0	-1	0	2	2	2	2	3	2
	Focus perspective	-2	-1	-2	0	1	1	2	2	3
	Internal team set-up	0	0	1	2	2	2	2	2	1
	Organisation set-up	-2	-1	1	2	1	2	4	2	1
Product	Design Type	-2	-1	-1	1	1	2	3	2	3
	Client input	0	0	1	0	1	1	0	1	0
	Design variety	-2	-1	-1	2	1	0	4	2	1
	Product configuration	-2	-1	-1	2	1	2	4	2	3
	Profit margin	0	2	2	-2	-2	0	-2	-4	-2
Production	Production rate	-2	-2	-1	2	2	2	4	4	3
	Production type	-2	-1	1	1	1	2	3	2	1
	Supply chain	-1	0	1	2	2	2	3	2	1
	Delivery time	-2	-1	0	2	2	2	4	3	2
	Strategy	2	0	0	2	2	2	0	2	2
	External relations	0	0	1	2	2	2	2	2	1
		0,0	-0,3	-0,5	1,0	1,1	1,0	2,2	1,8	1,5

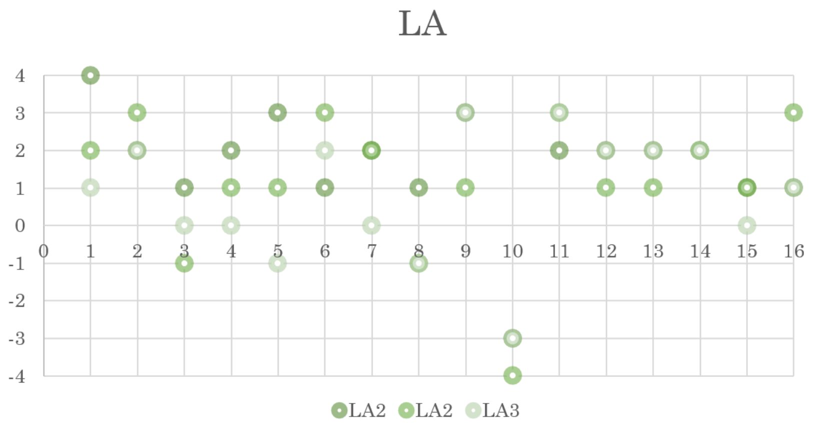
LM 0 LM 1

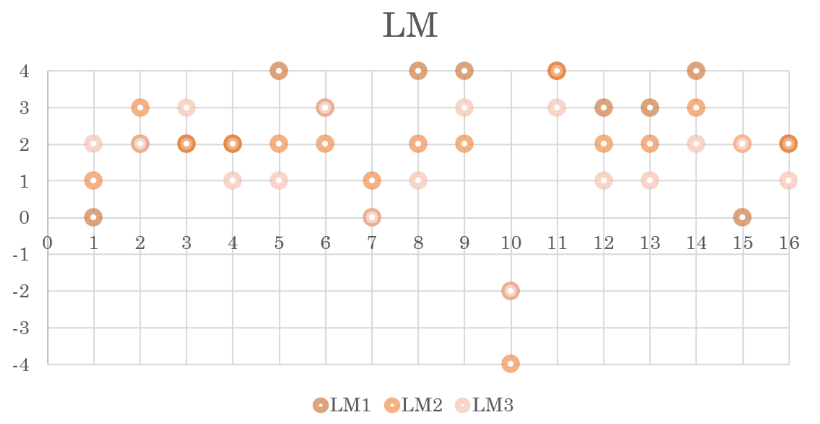
Departmental profiles: Graphical visualization.

Organization	1. Driver
	2. Innovation
	3. Focus perspective
	4. Internal team set-up
	5. Organisation set-up
Product	6. Design Type
	7. Client input
	8. Design variety
	9. Product configuration
	10. Profit margin
Production	11. Production rate
	12. Production type
	13. Supply chain
	14. Delivery time
	15. Strategy
	16. External relations









APPENDIX G - PD characteristics results explained

1. Profit margin

The results depict a the company that is experiencing low profit margins, but is looking to increase profit margins per module in the future. This suggests that they are looking to become more efficient and cost-effective in their production processes while still accommodating up to unique client needs.

2. Supply chain

Currently he company is experiencing a fragmented supply chain, but is looking to integrate the supply chain in the future. The trade-off here may be between securing a stable supply chain with key suppliers versus maintaining flexibility to switch suppliers.

3. Organization set-up

Lister Buildings is organized as a integrated company, however, currently they are experiencing a decentralized organization set-up. Nevertheless, the goal is to centralize the organization set-up in the future. This may be an effort to increase efficiency and coordination in the company.

4. Production type

The current production process is unique, but the company is looking to adopt a continuous production line in the future. This suggests that they are looking to increase efficiency and scalability in their production processes.

5. External relations, △ = 17,

The company is currently experiencing opportunistic relationships with suppliers, but is looking to form close supplier relationships in the future. This trade-off may be related to the tension between finding the best prices for components and materials and having a consistent and reliable supplier that can adapt to their requirements.

6. Driver, △ =16

There is a perceived discrepancy between Lister Buildings current focus on time-driven goals and their desired focus on price-driven goals. This could be due to a trade-off between meeting tight deadlines to deliver timely to the client and cutting costs in order to increase profitability.

7. Internal Team set-up, △ = 16

Lister Buildings results shows their struggling with their current use of short-term teams and their desired use of long-term teams. This could be related to the tension between the flexibility and adaptability provided by short-term teams and the increased efficiency and specialized expertise provided by long-term teams.

8. Strategy, △ = 14

This results indicates a difference between their current focus on agility and their desired focus on a more lean approach. This trade-off may be related to the tension between being able to quickly respond to changes in the market to stay relevant with unique offers and implementing a more systematic and efficient approach to production.

9. Focus perspective, △ = 13

Lister Buildings indicated a difference between their current focus on the designer/developer having the last say and their desired focus on manufacturing having the decision weight. This could be due to a trade-off between having more design freedom and having more control over the production process.

10. Design variety, △ = 10

The score of 10 suggests that there is a moderate discrepancy between the current and desired state of the company's design freedom. While the current profile of the company may feature a high degree of design freedom, the future profile aims for less design freedom. However, it is important to note that the difference in score is relatively low, and this discrepancy may not be significant. Additionally, trade-offs may have to be made between allowing for more design freedom, which may lead to more variability in production and potentially longer lead times or increased costs, and having more control and standardization in the design process for the benefit of efficiency and profitability.

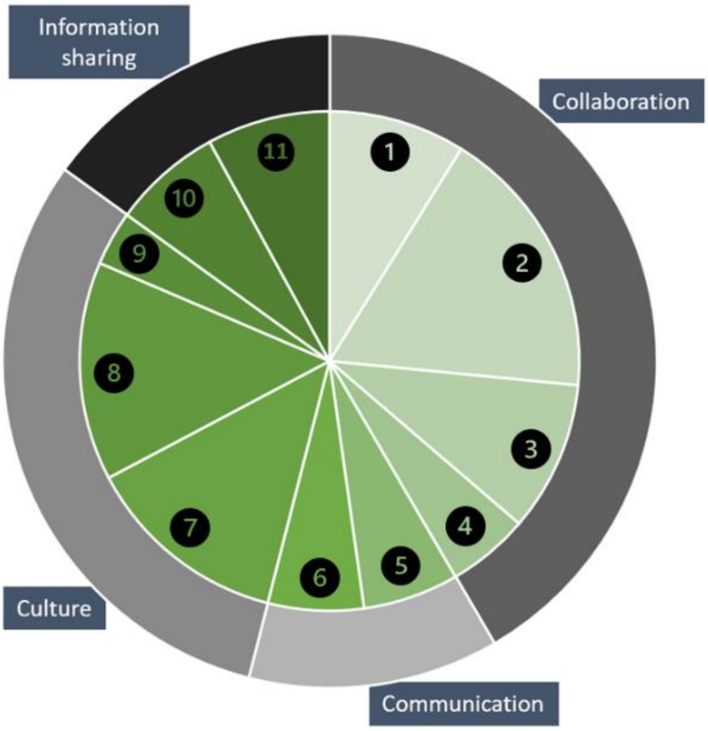
11. Client input, △ = 7

The "Client input" category pertains to the level of involvement that Lister Buildings currently allows for its customers in the design and development process of its products. The score of 7 suggests that there is a high degree of client input, however the ideal or future profile of the company aims for less client input with a score of -1. This trade-off could be due to the fact that more client input may lead to more variability in product design and potentially longer lead times or increased costs, or that the company wants to shift towards a more predefined product portfolio with less design freedom.

APPENDIX H - RESULTS CSFs

SYNEGRY

Communication



CSF 1 – EFFECTIVE COMMUNICATION

Effective communication is identified as a critical success factor for ensuring successful integration within the modular construction project. The interviews revealed that there is room for improvement in communication between the various stakeholders involved in the project, specifically between LA and LM. It was noted that LO could act as a connecting factor to improve this communication, and that LD could act as a supporting factor. One reason for the current communication difficulties is that the company is relatively new, and the team members are not yet well attuned to each other. Additionally, there were issues with decisive decision-making due to a lack of skills in this area. Miscommunications were also prevalent, due to the absence of feedback loops, differences in lingo or mode of communication and uncertainty about deliverables. These factors demonstrate the importance of effective communication in ensuring successful project integration.

CSF 2 – SHARED UNDERSTANDING IN MESSAGING

One of the CSFs that has been newly identified during the analysis of the interviews is shared understanding in messaging, among all stakeholders involved in the modular construction project. The insights gathered from the participants indicate that there are currently some challenges in achieving this factor. One of the main issues is the lack of a clear and consistent understanding of key terms and definitions related to the project environment and the modular construction process. These definitions are often chosen for convenience among internal and external parties, but do not necessarily lead to optimal results in the modular construction process.

Additionally, participants noted that the concept or terminology of "standardizing" is relative, as it can refer to both the project as a whole and individual products. This lack of a common understanding of key terms and definitions can lead to confusion and miscommunication among stakeholders, resulting in inefficiencies and delays in the project. To address this, it is important for all stakeholders to work together to establish clear and consistent definitions that align with the modular construction process and to ensure mutual understanding and common ground among all parties involved.

Mutual understanding/Common ground

According to Jassawalla and Sashittal (1998), mutual understanding and transparent interaction within cross-functional collaboration can be enhanced through the development of "mindfulness" and "synergy". Mindfulness refers to "team decision-making and actions which reflect an integrated understanding", while synergy refers to the ability of a team to generate innovative ideas through collaboration (Holland et al., 2000). These two elements are crucial for effective communication and shared understanding within a cross-functional team. In other words, effective cross-functional collaboration requires communicating the understanding of different perspectives and the ability to generate new ideas through teamwork. In a work setting, when employees from different departments or teams come together to work on a project and are able to find common ground and establish a shared understanding, it can lead to more productive and successful meeting.

Collaboration

CSF 3 – COLLABORATIVE WORKING ENVIRONMENT

A collaborative working environment is essential for the successful integration and coordination of the various players within the value chain of a modular construction project. However, in the case study of Lister Buildings, physical distance between the Weert and the Den Bosch offices was identified as a hindrance to achieving an overarching sense of togetherness. Despite being a relatively small organization, there is a focus on individual teams that can conflict with the need for a cohesive and collaborative business approach. While there are benefits to the short lines of communication and the ability to quickly bring other disciplines to the table, the hybrid nature of working and limited physical presence can make it challenging to foster a truly collaborative environment. Additionally, the difference in culture between the locations may also contribute to difficulties in fostering a cohesive and collaborative working environment.

> *"The distance between Weert and Den Bosch doesn't really help either. So that's another thing, we secretly suffer more from that than we think. It feels like an obstacle to getting behind each other's ideas and decisions more quickly as there are no informal moments."* ***– Manufacturer***

CSF 4 – LONG TERM PARTNERSHIP

The critical success factor of long-term partnerships is important for ensuring successful integration in the value chain of modular construction projects. One of the key positive aspects of long-term partnerships is that there are fewer misconceptions between partners, as they have a deeper understanding of each other's disciplines and goals. This allows for the development of trust and mutual understanding, which can lead to a more efficient and productive working relationship. Additionally, through regular feedback, partners can work together to identify and address areas of improvement, which can lead to ongoing growth and development. Furthermore, long-term partnerships provide a sense of stability and certainty, as partners are motivated by the same goals and objectives.

However, long-term partnerships also come with certain challenges. Partners may have higher expectations of each other, which can lead to increased pressure and the need for ongoing communication and collaboration. Additionally, maintaining these long-term relationships require effort to maintain trust, understanding, and communication.

CSF 5 – ESTABLISHED COLLABORATION STRUCTURE

During the early phases of the project, there was a lack of established work structure, which resulted in a disorganised approach to tackling the project. However, as the project progressed and external consultants were brought in, a more structured approach was implemented through scheduled appointments. Despite this improvement, there were still issues with the lack of prioritization for cooperation between different parties due to work pressure.

On a positive note, the importance of learning lessons from previous projects was recognized by the LA, LO, and LM teams, and regular meetings within teams were held to ensure that these lessons were shared and implemented in future projects. However, the structure was not as well-established between teams, and there were irregular meetings outside of teams.

CSF 6 – EARLY INVOLVEMENT OF KEY PARTIES

The critical success factor of early involvement of key parties is essential for the successful integration of the value chain in a modular construction project. This includes the involvement of key parties such as LO and LM at an early stage in the project. It was noted during the interviews that the LO is not always optimally utilized by other parties due to the fast-paced nature of the business. However, early involvement of these key parties can lead to the strengthening of cooperation and collaboration. Additionally, involving parties such as Manufacturing and Engineering at an early stage for manufacturability and having them actively participate in the project can be seen as a logical solution and can easily initiate collaboration. Furthermore, it was noted that the LD and the LO can play a role in strengthening cooperation. Additionally, LA should be involved at an early stage to ensure that all parties are aware of the project's goals and requirements.

Information Sharing

CSF 7 – EARLY AND EFFECTIVE USE OF INFORMATION/COMMUNICATION TECHNOLOGIES

During the interviews, it was identified that the level of awareness of the added value of Building Information Modeling (BIM) arrived quite late. Furthermore, the limited experience with BIM or other technological systems was highlighted as a bottleneck, as the company was considered too young to have this kind of well-established IT landscape. However, it was also noted that there has been recent awareness of the importance of BIM among all teams and that the first steps towards adoption of BIM are being taken within the project team. This highlights the need for early adoption of information and communication technologies to effectively manage and integrate the value chain in modular construction projects.

CSF 8 – FREQUENT INFORMATION/KNOWLEDGE SHARING

FREQUENT INFO SHARING

The critical success factor of "frequent information/knowledge sharing" is an important aspect of creating synergy in modular construction projects. During the interviews, it was identified that there is a lack of basic information being shared between LD and LM regarding design and realization principles. Also, the lack of an elaborated basic Plan of Action (PvE) for modular construction is also an area of concern, as it would allow for more efficiency by addressing common issues and avoiding repetition. The participants emphasized that creating a structure for regular knowledge sharing and a basic PvE for modular construction is a priority for the architectural team (LA) as it will result in a reduction of repeated efforts.

Culture

CSF 9 – TRUST AMONG EMPLOYEES

The critical success factor of trust among employees is crucial for the successful integration of cross-functional teams in modular construction projects. The participants in the interviews reported a high level of trust among themselves and towards each other within the company. This trust is built through long-term collaboration, repetition, and the ability to see improvements. The trust and confidence in their colleagues allows for open communication and the willingness to share information and admit uncertainty. The trust in the company's vision also allows for a willingness to adapt and be open to learning. However, there were also reports of misconceptions and unrealistic expectations due to a project-based interpretation through experience of product aspects, which can cause a lack of focus on certain aspects.

CSF 10 – MORALE AND MOTIVATION

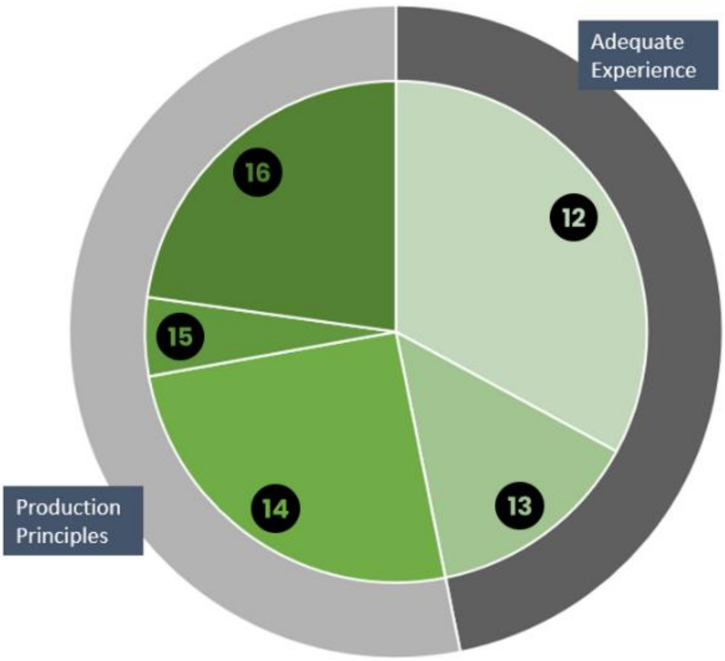
The insights from the interviews reveal that the employees at Lister Buildings share a common motivation for the company, which is reflected in the integrated working environment and the short lines of communication within the organization. This results in a strong sense of cohesion and commitment to the company's mission and values, with a majority of all departments indicating that they believe in Lister's vision of sustainable, integrated, innovative, challenging, future-proof and environmentally-friendly building solutions. This positive morale and motivation among employees is a vital aspect of ensuring a successful project outcome and a cohesive value chain.

CSF 11 – TOP MANAGEMENT COMMITMENT

"Top Management Commitment" is an important critical success factor for the successful integration of cross-functional teams. However, during the interview process, it was noted that there may be a slightly lower level of confidence among top management due to a large presence of traditional construction backgrounds among them. This can potentially impact the level of commitment to the project as they may draw too many lessons from traditional experiences. To mitigate this, it is crucial that top management communicates a strong and clear vision for the project and actively works towards aligning the team with this vision. Additionally, a good intention alone is not enough to effectively execute a modular construction project, a real commitment and understanding of the specific method is needed.

COMPETENCE

Adequate MC experience



CSF 12 – ADAQUATE TECHNICAL AND PRACTICAL EXPERIENCE AND KNOWLEDGE

Having "adequate modular construction experience" is crucial for the success of a modular construction project. The lack of experience among the team members can lead to a lack of understanding and a lack of collaboration between different parties. The interviews revealed that, in the case of Lister Buildings, the lack of experience among the team members was an obstacle in the industrialization and product development process. The team members were aware of the importance of adequate experience, but the lack of it resulted in a tendency to think quickly in traditional structures, instead of an agile and BIM-based approach. Furthermore, the interviews highlighted that the team members at Lister Buildings were understaffed to scale, which prevented them from scaling up within the given time. The start-up environment in the company also led to job gaps that needed to be filled until a specialist could be hired for the role.

CSF 13 – MATURING OF TECHNIQUES THROUGH RETROSPECTIVE FEEDBACK

The critical success factor "maturing of techniques through retrospective feedback" highlights the importance of gathering retrospective feedback from team members and stakeholders in order to improve performance in modular construction projects. However, in practice, the participants in the case study mentioned that they were not able to gather such feedback because they did not have the time. They shared that they needed more time to learn from their mistakes and improve the next project. The participants also noted that their projects were overlapping, which made it difficult to take the necessary lessons learned from one project and apply it to the next. Despite this, they expressed confidence in their ability to grow as a company by actively incorporating feedback retrospectively and understanding the consequences of modular building. LA plays an important role as an intermediary for common understanding within the company. Additionally, the regular reporting between LO and LM is seen as a step towards incorporating feedback. However, it is also noted that the LD lacks the basic information to be shared by LM such as design principles and the realization principles.

Production principles

CSF 14 – EARLY DESIGN FREEZE

The early design freeze is an essential aspect of successful modular construction projects to minimize the risk of costly design changes and ensures the success of the project. However, the lack of a standardized product and a lack of a first version in the design phase makes it difficult to capture the design early. This has been an issue in the past with no standardized product as a starting point and no first version, which causes disagreements and confusion throughout the design. Furthermore, there is a need for the involvement of LM to agree with the captured design, in order to prevent any potential issues down the line in the project. Additionally, it is important to implement an early design freeze to ensure that the design phase is accurate and complete, so that the next stage of production and manufacturing in the supply chain hierarchy can start on time.

CSF 15 – DEFINED DESIGN & TECHNICAL SPECIFICATIONS OF PRODUCT

According to the insights from the interviews, it is clear that there is currently no standardized product at Lister Buildings. This presents a number of challenges for the different parties involved in the project, including the developers, architects, engineers, and manufacturers. Developers have no basic module information to work with, making it difficult to capture designs early in the project. Additionally, architects are still approaching assignments in a traditional way, which leads to many different dimensions in the project. engineers also miss the translation battle between design and manufacturability, leading to a lack of repetition in the production process. Furthermore, there is currently a lack of standard module sizes that take into account factors such as factory and transportation needs.

According to the interviews, there is a need for a standardized product (80%), with reasonable design freedom (20%) to work with fundamental starting points. This will enable a more efficient build process and allow for more repetition in projects. The philosophy for standardization is present, but there is not yet a clear understanding of what the product should be. There is a lack of standardization that results in extra work for everyone, including in the work preparation process.

CSF 16 – SCALABILITY THROUGH STANDARDIZATION AND PRODUCT CONFIGURATION

Standardization and product configuration are crucial for scalability in modular construction projects. However, the interviewees from Lister Buildings had differing opinions on the level of standardization that should be implemented. While the LD emphasized the need for design freedom, other teams, such as the LA and LM recognized the importance of a standard product for scaling up the company. They see the ideal solution as a balance between having a manufacturable product that can handle exceptions while also being able to serve a large part of the market through a standardized variety of modules. The company is still in its early stages and as such, scaling up is difficult as they still have no standard product, no specific focus on the kind of organization and flow in factory, also they do everything 3D/2D/hybrid and complex/diverse projects. To achieve scalability, the company needs to focus on limiting the number of modules, separating standard and unique parts in their projects and implementing a separate production line for standard parts while focusing on unique process mapping.

Scalability through standardization and product configuration

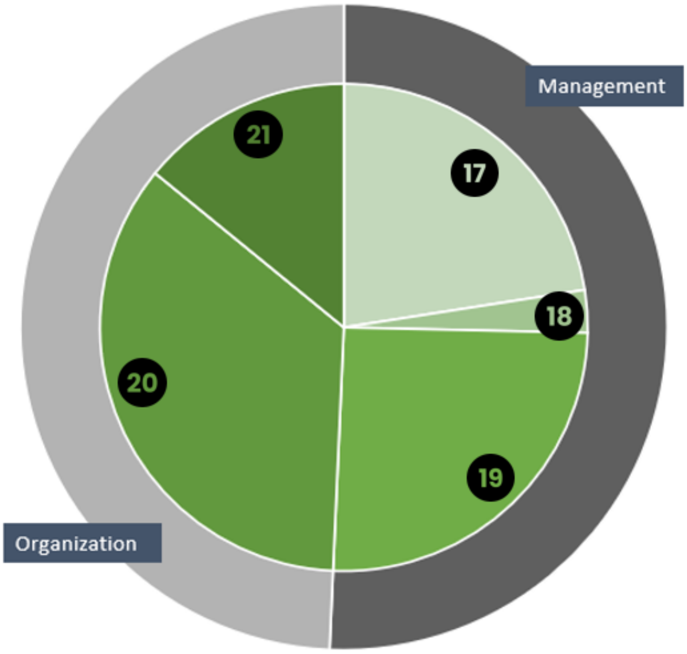
Standardization helps to reduce costs by allowing for mass production using the same materials, elements, equipment, and processes. It also improves efficiency through the specialization of labor and automation of production processes. By standardizing the design and production of modular components, companies can streamline their manufacturing processes, resulting in increased efficiency and lower costs. Product configuration, or the ability to customize modular components to meet the specific needs of a project, is *"putting together a product from well-defined building blocks (modules) according to a set of predefined rules and constraints"* (Sandberg et al., 2016). Modular construction companies can increase their appeal to a wider range of customers, leading to an increase in sales and revenue. Being able to quickly and easily customize modular components can reduce lead times and improve project delivery and increase its competitiveness in the market (Wuni & Shen, 2019).

Overall, the combination of standardization and product configuration allows modular construction companies to increase efficiency, volumes, reduce costs leading to economies of scale (Gann, 1996) and better meeting the needs of their customers, all of which are important factors in achieving scalability in the industry.

By standardizing modules to design building projects though the help of product configuration, stakeholders in the value chain, such as designers, manufacturers, and contractors, can work more efficiently and effectively together to deliver high-quality projects which contributes to the integration of the value chain. This is due to the design requirements being well-defined; streamlining and optimizing the various stages of the construction process.

VALUE SYSTEM MANAGEMENT

Management



CSF 17 – COORDINATION BETWEEN INTERFACES

The critical success factor of coordination between interfaces in value chain management is a crucial aspect in achieving successful modular construction projects. The insights from the interviews suggest that there is a need for improved contact between the different teams involved, particularly between the architects and manufacturers. LO can play a key role in connecting the different teams, while the LD can provide support in coordinating their efforts. The developer is traditionally seen as the project leader, however, when it comes to the product, LA or LO teams may take on a larger role as the product leader. LA is also seen as the most important intermediary in coordinating the different parties. Effective leadership and transparent planning are essential in ensuring successful collaboration between all teams involved.

CSF 18 – LINK BETWEEN DESIGN AND PRODUCTION

This critical success factor is another addition to the existing CSF-list. "Link between Design and Production" has several insights and areas for improvement in terms of value chain management. One major issue that has been identified is the gap between the design side and the production side. This gap is caused by a lack of communication and collaboration between the two sides, resulting in a lack of understanding and knowledge of the design and production processes. This can lead to issues such as translation report errors and miscommunication between the different departments, which can have a negative impact on the overall efficiency and success of the project.

To improve this, it has been suggested that LM needs to be more involved in the design phase, to help bridge the gap and ensure that the design is feasible and manufacturable from the start. Additionally, the company is facing shortcomings in personnel, especially in terms of work planners and people with product experience, which is also contributing to the gap.

To address this, it is important to have someone with both project and product knowledge, who is present from the beginning of the project and aware of the technical characteristics and performance of the module and runs with the whole project, is important for translation. In addition, the role of LO, as the glue in that because they deal with integrating the design with everyone else has been identified as an important role in filling the gap between design and production.

It is also mentioned that the company is lacking a project management branch, which is crucial in ensuring that the design is translated correctly to production and that all the parties are working in coordination. The key is that the development of a standard product would help in fixing routine in design, which will lead to an early involvement of LM, which in turn will lead to a more efficient translation to production.

Link between project/design and product/production

In the complex and fragmented processes of modular construction, there is a risk of various schedule delays, particularly those related to information. One issue is that stakeholders, often from different companies, are protective of their own interests and do not have a culture of sharing information. It's important to link the design and construction to avoid the "over-the-wall" problem that occurs when builders are left to interpret designs they weren't involved in creating (Wuni, Shen, & Osei-Kyei, 2022). This can result in "information islands," or disconnected bodies of information that need to be shared. These information islands can lead to schedule risks, such as a gap in design information between the designer and manufacturer, or inconsistency in logistics information (Li et al., 2017). These issues can result in significant delays in modular construction projects, particularly in those with shorter schedules and higher hourly rates for assembly equipment. Therefore, it is important to ensure consistency in information sharing within the integrated value chain to facilitate this smooth project delivery and coordinate the process between the two environments (Wuni, Shen, & Saka, 2022). Having the same person on multiple teams can facilitate information transfer. When several products have similar components, teams can share information through a "systems coordinating team." These teams provide support and purchasing efficiency for specific components or systems across multiple products. (Holland et al., 2000).

Organization

CSF 20 – CHANGE IN DEVELOPMENT PROCESS

Another addition formed from multiple interviewee statements is the change in the development process of the company. It is currently seen as too traditional and not optimal for modular construction in certain areas. The expert workshop that was held was seen as useful, but it was noted that it was a bit superficial at the front end of the process. It was suggested that another session should be held to delve deeper into the Technical Design (TO) phase and during the UO phase.

One key insight is that if the product is fully developed and understood, with all the necessary technology incorporated, then it is possible to be able to skip the VO and move directly to the SO to DO phase, thus shortening the development phase. This is because the acquisition phase is out of the company's control, but the development phase is not.

Another insight was that with more technology already incorporated in the modules, there may not be a need for a TO phase. The suggestion was made to create project teams within Lister for maximum collaboration, and to classify the process differently in order to shorten it and possibly even skip the VO phase.

The role of LM was also mentioned, as they are often seen as only responsible for the production of the product. However, it was pointed out that they should be involved earlier in the process to give input on what can be made. Overall, the process of approaching a project was seen as being too traditional and there is a need for a change to make it more efficient.

CSF 21 – EFFECTIVE ALIGNMENT ON RESPONSINBILITIES AND EXPECTATIONS

In order to effectively align on responsibilities and expectations within the value chain management, it is important to clearly define and separate the responsibilities of each team. For example, LO works on the development of systems, while LM is responsible for producing the final product. LA designs a quality project that is in line with the product that LM produces. LD works towards ensuring the feasibility of the project and provides necessary resources. While each team has its own specific responsibilities, it is important for them to work closely together and have a clear understanding of each other's deliverables and responsibilities. This can be achieved by creating a clear organizational distinction, such as separating responsibilities based on project (building) or product (module) level, and having transparency in responsibilities. However, due to the startup environment, there may be some overlap in tasks and responsibilities, so it is crucial to have joint coordination to ensure the success of the project.

Effective alignment on responsibilities and expectations between value players

It is important for value chain players to agree on their roles and expectations in order to enhance cross-functional integration and foster productive relationships. This can be achieved through role formalization, which clarifies responsibilities and dependencies between functions. In order to be effective, team leadership should be dedicated to one project, with a clearly assigned and accountable team leader. All team members should be fully dedicated to the project, with their first loyalty being to the team or project rather than the function. It is also important for there to be strategic alignment between functions, with all senior managers being supportive and in agreement on the prioritization and commitment to projects. This will help prevent isolation of cross-functional teams and ensure their success. (Holland et al., 2000; Yuen et al., 2019)

Having clear alignment between key players on the responsibilities and expectations of a modular construction project can lead to effective achievement of planned objectives and satisfaction of stakeholders, according to (J. O. Choi, 2014). When all key stakeholders understand and agree on the goals, objectives, and benefits of using MiC, they are more likely to work collaboratively and coordinate effectively, reducing conflicts and delays in project delivery. Aligning on responsibilities and expectations can therefore be a key driver for successful collaboration among the key players in a modular projects (Wuni, Shen, & Osei-Kyei, 2022).

“Ain't nothin' gonna break my stride
Nobody gonna slow me down
Oh no, oh no, I got to keep on moving”

Break My Stride by Matthew Wilders

Lister Buildings
THE REAL ESTATE LIFECYCLE COMPANY

TU Delft
Delft University of Technology