Lappeenranta University of Technology LUT
School of Engineering Science
Degree Programme in Industrial Engineering and Management

Juha Eloranta

Changing traditional construction with modular design platforms

Supervisor: Prof. Janne Huiskonen
Advisor: M.Sc. Otto Alhava

ABSTRACT

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Juha Eloranta

Changing traditional construction with modular design platforms

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Keywords: residential construction, modularisation, modular design platform, industrial construction, project-independent thinking

To improve productivity and to address increasing demand of affordable housing, construction companies should find a way to industrialise their production. One important aspect in this industrialisation process is to rethink the design process. By utilising modular design platforms with predesigned standardised components construction companies can possess a great potential to improve their productivity and create value to their stakeholders. The aim of this research was to study how modular design platforms could change the traditional residential construction and define a modular construction concept for the target company's residential construction unit. This was carried out by creating a modularisation strategy model and a maturity model for the target company's modular design platform development project.

The study was carried out as a design science research where the first phase focused to find out an adequate framework by conducting a literature study about modularity and modular design platforms. Based on the findings from the literature study and semi-structured interviews, the second phase focused to develop a modularisation strategy and maturity model for the target company. The generated new information was exploited during development team meetings and finally the models were evaluated by Fira's management and modified according to the feedback.

In this thesis was found that modular design platforms are successfully implemented and gained good results in the Norwegian ship building industry as well as in some extent in Finnish shipbuilding industry. In the ship building industry modular design platforms have increased suppliers R&D investments and reduced projects lead time, enabled cost savings as well as impacted to design decision power on the market level. A successful modularisation process in construction requires clear objectives, strategy and a method to assess the current state of modularisation. Finally, the modular design platforms could enable the rise of project-independent thinking in residential construction.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
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Tuotantotalouden koulutusohjelma

Juha Eloranta

Perinteisen rakentamisen muuttaminen modulaarisen suunnittelualustan avulla

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Hakusanat: asuntorakentaminen, modularisaatio, modulaarinen suunnittelukirjasto, teollinenrakentaminen, projektiriippumaton ajattelutapa,

Parantaakseen tuottavuutta ja vastatakseen kasvavaan edullisen asumisen kysyntään, on rakennusliikkeiden löydettävä keinoja asuntojen teolliseen tuotantoon. Suunnitteluprosessin uudelleen ajattelu on yksi tärkeä näkökulma meneillään olevassa rakentamisen teollistumisessa. Modulaaristen suunnittelualustojen ja vakioitujen ratkaisujen käyttäminen saattaa sisältää merkittävän potentiaalin parantaa tuottavuutta ja luoda arvoa sidosryhmille. Tämän tutkimuksen tavoite oli tutkia, kuinka modulaarinen suunnittelualusta voisi muuttaa perinteistä rakentamista, sekä kuvata kohdeyrityksen asuntorakentamisen yksikölle modulaarisen rakentamisen konsepti. Tämä toteutettiin luomalla modularisaatiostrategiamalli sekä modulaariseen suunnittelualustaan liittyvä maturiteettimalli.

Työ toteutettiin suunnittelututkimuksena, jossa ensimmäinen vaihe keskittyi määrittämään sopivan kehyksen myöhemmin luoduille malleille kirjallisuustutkimuksen avulla. Perustuen kirjallisuustutkimuksen löydöksiin sekä teemahaastatteluihin tutkimuksen toisessa vaiheessa kehitettiin moduarisaatiostrategiamalli ja modulaarisen suunnittelualustan maturiteettimalli kohdeyritykselle. Tuotettua tietoa hyödynnettiin kehitystiimin työskentelyn aikana sekä lopulliset mallit päivitettiin kohdeyrityksen johdon palautteen perusteella.

Tutkimuksessa havaittiin, että modulaaristen suunnittelualustat ovat tuottaneet lupaavia tuloksia sekä norjalaisessa, että suomalaisessa laivanrakennusteollisuudessa. Laivanrakennusteollisuudessa modulaariset suunnittelualustat ovat lisänneet toimittajien tuotekehitys investointeja, lyhentäneet tuotantoaikoja, mahdollistaneet kustannussäästöjä sekä vaikuttaneet markkinatasolla päätösvaltaan suunnitteluratkaisuissa. Onnistunut modularisaatio rakentamisessa tarvitsee selkeitä tavoitteita, strategian sekä mallin arvioida modularisaation edistymistä. Lopuksi, modulaariset suunnittelu alustat saattavat mahdollistaa projektiriippumattoman ajattelutavan vahvistumisen asuntorakentamisessa.

ACKNOWLEDGEMENTS

Modularisation and modular platforms were not very familiar terms for me before the spring 2020 when the planning of this thesis started with Fira's residential development unit. Despite the unknown area, the possibility to be part of creating something new in the construction industry felt an interesting possibility. Of course, at that time I didn't have any idea how broad and complicated this topic would be. However, after Tero Vanhanen showed couple of power point slides it was too late to think this kind of matters. Although the corona time was a tough time for me and other people, I was able to use this time to work with my thesis in Karlsruhe and later in Zürich without fearing missing out something.

First, I would like to thank the development team members Santtu Hokkanen and Tero Vanhanen who gave me the possibility participate to the development process and listened my opinions. Secondly, I would like to thank my mentor Otto Alhava who encouraged me and saw some value in my work when I didn't see it anymore. I would like to also thank my supervisor professor Janne Huiskonen for valuable comments and guidance during the thesis project. Moreover, I would like to express my gratitude for all interviewees who invested their time.

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Juha Eloranta

Juha Eloranta

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List of abbreviations

CMM	Capability maturity model
CMMI	Capability maturity model integration
CSC	Construction supply chain
DSR	Design science research
HAVAC	Heating, ventilation, and air conditioning
IC	Industrialised construction
LEED	Leadership in Energy and Environmental Design
MDP	Modular Design Platform
MDL	Modular Design Library (=modular design platform)

1 INTRODUCTION

1.1 Research background and motivation of subject

People are moving more and more from rural areas to cities which creates a great pressure for cities to grow. The global challenge in this urbanisation trend is the lack of affordable housing. To address this problem the construction industry must find new ways to improve its productivity. For decades construction productivity and performance has lagged compared to other manufacturing industries. During the last 20 years the productivity of the construction business has improved yearly by just about 1%, when in manufacturing industries the improvement in productivity has been much higher (Meindel 2018). There is lots of research about how the construction industry should apply manufacturing industry practices, but successful implementations are still scarce in the industry. However, manufacturing industries and the construction industry have of course their own characteristics which have to be considered as well. While many manufacture industries can be defined as process-based industries, construction is often described as a project-based industry (Behera et al. 2015). Construction projects are often complex, unique and non-recurring which sets barriers to standardisation and repetition (Bertelsen, Koskela 2005). Moreover, construction is a heavily regulated, very fragmented and cyclic industry where production happens at the building sites and holds a very complex stakeholder network (Barbosa et al. 2017, Vrijhoef, Koskela 2005). As a result, a construction projects are often designed and performed poorly. Moreover, short-term-thinking leads to maximising profits in the short term, and investments in research and development (R&D) remain at low level (Behera et al. 2015).

Various attempts have been made to replicate manufacturing industry practices and this movement has been called “industrialisation”, or in other words, the traditional construction culture is transitioning towards the manufacturing industry culture (Behera et al. 2015). One example is standardised building elements which have been widely used since middle of the nineteenth century. However, prefabricated building elements have not changed the culture much, and again maximising a single project profit is the common attitude. Recently, this movement has occurred in construction as implementation of new process management tools and lean practices. For instance, tools such as Last Planner System, Big Room methods and Takt-time planning have been recently implemented in the construction industry and some promising results have been achieved. However, those methods do not completely address the basic problems (the uniqueness, complexity, fragmented industry and short-term thinking etc.) and therefore deeper change is required in the construction industry. In literature, modularity and prefabrication have been lately one popular approach to address to the low productivity of construction (Barbosa et al. 2017). Aapaoja and Haapasalo (2014) argue that the greatest benefit of modularity and prefabrication is the changing mindset from a project-focused to a project-independent mindset.

If we look at other fields there are many successful modularity implementations in manufacturing industries such as the car industry and the computer industry (Bekdik 2017). Moreover, good results have been seen in the shipbuilding industry which has many similarities with the construction industry (Erikstad 2019). The common factor for these successful modular production systems is a product platform that uses standardised components or modules with standardised interfaces. In turn, the successful product platforms are still scarce construction, and use of modules is still at a low level, and additionally interfaces of components are often not well designed, or tolerances are in comparison loose. Barbosa et al. (2017) in their report state that reinventing designing methods in construction could improve the whole project productivity up to ten percent. In practice, this could mean standardised design processes and modular design platforms are utilised. Perhaps the design platform thinking could be an important missing piece in industrialisation of construction.

1.2 Motivation and selection of the subject

The project-based thinking is deeply rooted in the construction industry and it has a great negative impact to long-term development in construction supply chains (CSC). In literature, a product platform, or in other words, design platforms have proved to increase long-term development with suppliers and other partners. While ideas about product platform in residential construction are not new, the successful implementations are still scarce.

This research is done as an assignment from the case company Fira Oy (later Fira) and it is part of a development project called “modular design library”. The thesis also engages to Fira’s strategy where Fira strives to create value by increasing modularity, using tack scheduling and by exploiting digital management tools. Fira is a Finnish construction company who wants to change the culture in the Finnish construction industry and implement new ideas outside the industry. Fira’s business focuses on project development and construction in following fields: residential construction, commercial construction, modernisation and pipe renovations. In 2019, Fira’s net sales were €217.7 million and its residential construction unit’s net sales reached €76.4 million. In 2018 Fira launched a bold vision “towards free housing” and strives to find ways to make a better quality and affordable housing but at the same time have successful business.

Over a year ago, Fira started a development project called “Modular design library” (later MDL) which strives to create a design library that uses standardised design solutions, components and modules. However, the creation process of MDL is very complex, and among Fira’s organisation the final result has not been clear. Moreover, there has been a lack of understanding about how MDL could change traditional supply chain, and what kind of changes that could mean in Fira’s own organisation. Fira also has other initiatives related to modularity. For instance, Fira cooperate with Lujabetoni to develop a new baffle plate solution (called Superlaatta) which is pre-sressed concrete plate with electricity tubing and floor heating system.

Moreover, Fira has its own module development and production in prefabricated balcony modules (called Noppaparveke) and in bathroom modules (called Modules). Although, these initiatives have been innovative and successful to some extent, they also have faced some problems in a large scale utilisation.

A design solutions selection process and modularity has been studied earlier in Master of Science Thesis by Kauppila (2019). Kauppila (2019) pointed out the significance of standardised design solution as well as discussed, the single component design decision process from cost perspective. In turn, Lehtovaara (2018) in his Master of Science Thesis developed learning models and feedback channels in design management process. Both above mentioned studies have also created a significant base for this research which focuses on the creation process of platform that aim to utilise standardised components and enable faster learning. While Fira now strives to increase modularity and create the modular design library with standardised solutions, it is important to have a clear plan and strategy which answers questions why and how modularisation should be performed.

1.3 Research Objectives and Research Questions

The recent studies indicate that modularity plays a role in the construction industrialisation and productivity improvement. Modular design platform should especially be seen as an important part in the shift towards industrialised production. However, successful implementations in the construction industry are still scarce. The aforementioned factors in the introduction chapter enable us to form the research problem: **”How to define modular design concept and how it could change the traditional residential construction towards industrialised construction?”**

The main objective of this thesis is to bring more clarity to what kind of modular design library would best fit for the case company Fira, and more specifically for its residential construction unit. The goal is to create a strategy model that clarifies and synchronises the Fira’s strategic objectives for modular design library, and to create a maturity model for MDL which suggests the direction for its further development. To gain a broader view, this thesis also explores the ship building industry, and how modularisation has been implemented there. The change from the traditional project-based thinking towards the project-independent thinking may also require changes in the company’s supply chain. Therefore, this study also focuses on the identification what kind of changes are necessary in Fira’s supply chain.

The research objectives are addressed with the following research questions (RQs) and their sub-questions:

> **RQ1: How to define modular design concept and how it could change the traditional residential construction towards industrialised construction?**

RQ2: What kind of changes the modularisation has caused on supply chains in the ship building industry and is it possible to apply good practices in the Fira's residential construction?

RQ3: How stakeholder's interests should be taken into account in modular design library's creation process and how projects performance should be followed in the future?

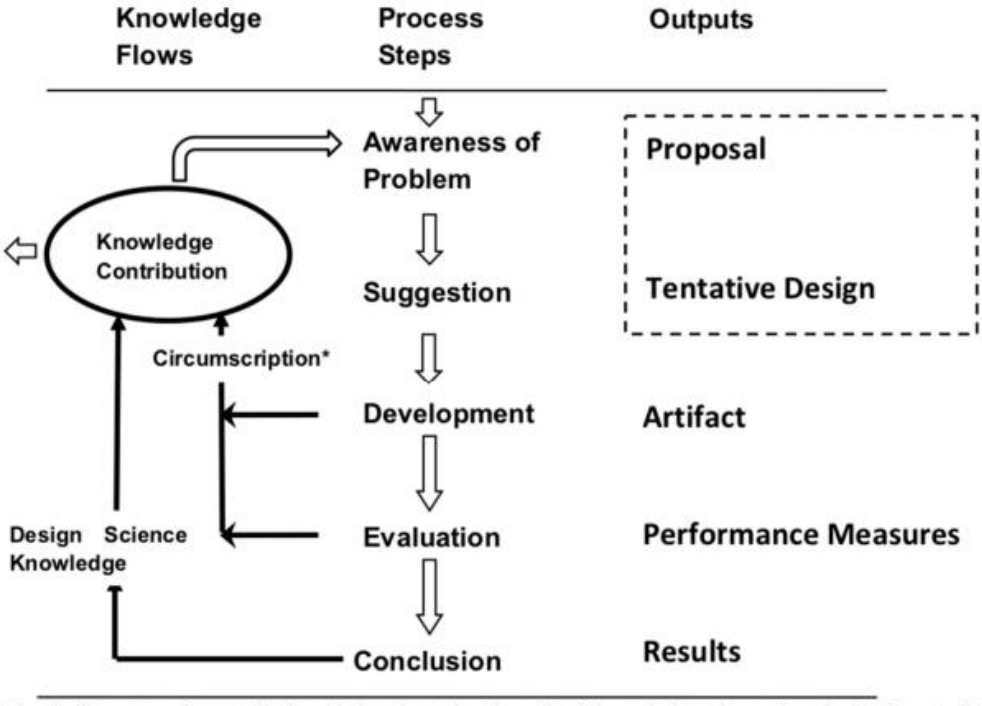
The research focuses on the modularisation in residential construction context. More specifically, the research addresses "design and build" type residential production. The research emphasises modularisation strategies in concrete construction but covers also other building materials in a narrow extent. Because concrete has some limits for a module size, this research does not deeply review apartment size volumetric modules. Instead, this research focuses on "hybrid modularisation strategies" or in other words, strategies which utilise both off-site manufacturing and site-manufacturing processes. In addition, because the subject is so broad, the research focuses mainly on changes in activities that happen before the production phase.

1.4 Research strategy

Research strategy

In this research, Design Science Research (DSR) methodology is chosen because it focuses on the development of actual artifacts, such as products, processes, software solutions, models or systems. DSR is used in construction and other engineering fields because it provides a more practical approach to do research and develop those above outcomes (Kanjanabootra 2016). Also, Aken et al. (2007) support utilising design focused and theory-based problem solving in this context. The theory-based problem solving doesn't mean copying and utilising theories straight from literature, but rather theories have to be contextualised for the actual problem and creatively used to design a solution (Aken et al. 2007). If we compare to natural sciences, the significant difference between natural sciences and design science is that natural sciences aim to understand reality, while design science strives to create artifacts that serve human needs (Hevner, A. R & al. 2006). Consequently, it is justified to say that DSR-methods serve this research objective to design and define the modularisation strategy model and the maturity model.

Characteristic for DSR-method is its stepwise approach and solution development in cycles that contains theoretical and practical aspects. According to Vaishnavi et al. (Vaishnavi et al. 2004) DSR-process contains five steps that are presented in figure 1 below.



* Circumscription is discovery of constraint knowledge about theories gained through detection and analysis of contradictions when things do not work according to theory (McCarthy, 1980)

Figure 1 Design Science Research process (Vaishnavi & Kuechler 2004/19)

The DSR-process starts with making oneself aware of the problem. This step comprises the definition of the research problem and justifying the value of a solution. The definition of the research problem usually requires conversations and iteration with the principal company (Vaishnavi et al. 2004). Also, visualising the problem with tools like cause-and-effect diagram helps to understand the problem (Aken et al. 2007). The output of the first step is a proposal for the research which can be transformed into research questions. The following step is called the "suggestion phase" that can be seen as partly integral with the "problem awareness" step because proposal should also contain ideas of how to solve the problem. The Suggestion phase output is a tentative design of the solution to the problem. Gaps in knowledge and deficient design to solve the problem are characteristic for tentative design, and therefore the design needs to be improved and implemented in the "Development phase". The Development phase finally produces the complete artifact that is evaluated in the next step. Evaluation is based on qualitative estimation and quantitative measure of how well the designed artifact functions and meets the set objectives. The Suggestion, the Development and the Evaluation steps form an iteration loop that contributes with the principal during the research. The outcome from this iteration loop is finally concluded when well documented results of the research and the design science knowledge is communicated with the principal and other researchers. (Vaishnavi et al. 2004).

1.5 Structure of the research

This research is divided to five main parts presented in Figure 2. Again, the structure and content of phases are described below.

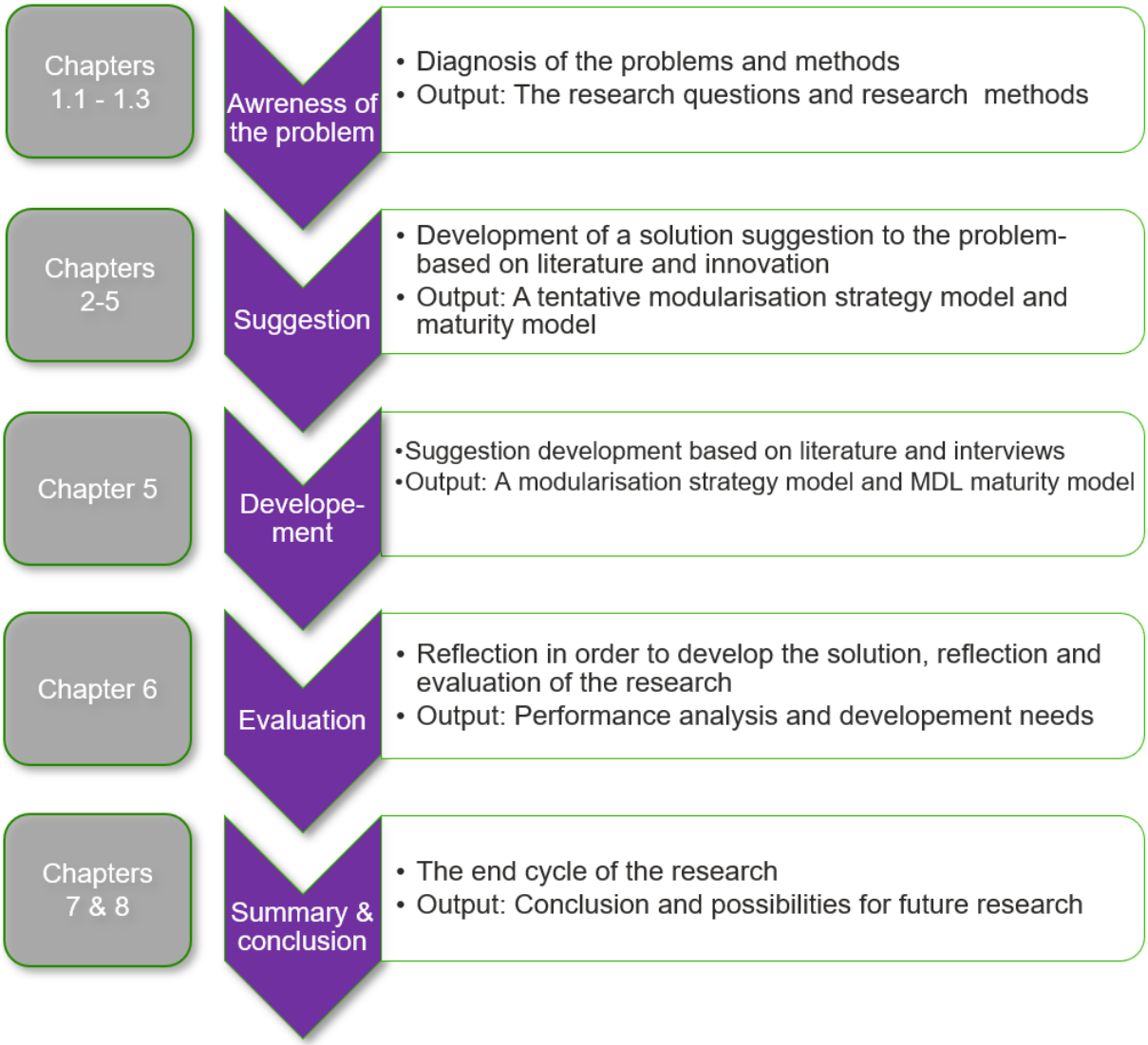


Figure 2 Structure of the research

Awareness of the problem

The first step is to identify the problem in the case company. This phase strives to get familiar with the current development project (MDL) and to seek the root causes for the current problems. In the awareness phase the existing research and observation of the problem based on the current state of an organisation are combined. The research motivation and selection of the subject is presented in chapter 1.2. Again, the research objectives and the specific research questions are formulated in chapter 1.3.

Suggestion

The development of solution suggestion starts by conducting a literature review. Chapter 2 strives first to formulate the characteristics for residential construction and major problems that obstruct improvement. After defining the major problems and characteristics chapter 3 focuses on possible solutions to address to these problems. More specifically, chapter 3 begins by covering basic theory of modularity and proceeds to modularity in ship building, and again to modularity in construction. In chapter 4 the findings of the literature review are summarised. Moreover, the current situation is mapped out by participating in to steering group meetings and workshops as well as conducting semi-structured interviews. The case company's current situation and interview process are presented in the chapter 5. In the chapter 6 the development suggestions are formulated based on the literature findings and interviews analysis. Furthermore, based on development suggestions and analysis, the tentative strategy model and tentative maturity model are formulated.

Strategy model and maturity model development

The purpose of the development phase is to present tentative models to the case company's organisation and receive feedback. Based on feedback the final forms of created artifacts are updated.

Evaluation and conclusion

In chapter 8, the performance of the research process and degree of problem solving are evaluated. Also, the further development needs for the case company are identified and presented. In addition, the scientific contribution of the research is evaluated, and limitations of the study are discussed. Finally, the conclusions of the research are presented and the possible subjects for further research are introduced.

2 TRADITIONAL RESIDENTIAL CONSTRUCTION AND INDUSTRIALISED CONSTRUCTION

2.1 Characteristics of traditional residential construction

Construction is often seen as a project-based industry that traditionally produces complex and unique products (Ballard, G., Howell 1998). Koskela (1998) lists characteristic attributes for construction: "one-of-a kind nature projects, site production, and temporary multiorganisation". The same general definitions also suit the residential construction industry, which refers in this research to production of multi-floor residential buildings. What are the other characteristics of the residential construction? — To obtain a better understanding in this specific construction sector, the following chapters strive to address this question more deeply.

2.1.1 Building as a product

Immobility

A residential building as a product has many characteristic attributes that are essential to consider when we study its supply chain. First, the residential building is attached to ground, which separate it from the most of manufacturing industry's products (Ballard, Howell 1998). For instance: soil conditions, seismic activities, groundwater level, social and environmental impact of the project are all factors related to a building's location, and which construction companies have to deal with (Bekdik 2017).

High level impact

Compared to other products buildings have a relatively long lifecycle and a high social impact. In Europe, it is common that buildings are designed to last at least 50-100 years (Eurocode 1990), and many already existing buildings are even hundreds of years old. Residential buildings also can be remarkably large or high constructions, and therefore they can have a great impact on an urban or a rural landscape. For instance, a new residential block or one new high-rise building can change a neighborhood's appearance significantly for the next 100 years. Also, the social impact of residential buildings is a notable aspect. Allard (1993) states that the housing conditions are one of the major factors of well-being. According to Allard (1993), a built-up environment should be designed to respect people´s social needs and enable self-actualisation. Not only humans are impacted by construction, but also the nature and animals have to be taken into account. In Finland the ministry of environment, the local city authorities and the Finnish environment institute (SYKE) in co-operation control and evaluate environmental impacts of the residential construction industry (Ministry of the Environment).

Uniqueness

Almost every residential building project is unique. There are many reasons why building projects are distinctive. For instance, authorities have their own complex regulations for different areas and customers have a relatively great power to impact the design process

(Vrijhoef, Koskela 2000). Also, the design process itself affects to buildings uniqueness. Traditionally, the project design process starts from the beginning by an architect's conceptual design and repeats every step without widespread exploitation of predesigned modules or design solutions (Bekdik 2017). Also, organisation changes are slightly different from project to project and have a great impact on the unique nature of production of residential buildings (Ballard, Howell 1998).

2.1.2 Construction process

Time lag

Residential construction projects contain several different stages and traditionally those stages take a long time. A single building project from the early design phase to the complete building can take several years. Because projects last so long, in many cases changes occur in project conditions and demands, which cause time lags to the projects. For example, customer's financial problems, delays in city authorities' processes, individual right of appeal and changes in political atmosphere are reasons for project delays. (Gidado, Kassim 2004, Ministry of the Environment).

Amount of work tasks and interfaces

The amount of work tasks in conjunction with a great number of interfaces that need to be put together during the design and the production phase at a building site are factors that increase the complexity. Often these interfaces are not well designed and cause problems during the production phase. Moreover, in a building site tasks are often executed simultaneously in a restricted area and in fluctuating weather conditions. (Gidado, K. I. 1996, Gidado 2004).

Atmospheric conditions

Compared to other manufacturing industries, the construction happens usually outside and hence is subject to weather conditions. Changing circumstances make long-term planning challenging and surprises can add uncertainty to project schedules. Because of wind, snow, cold and rain the planned productivity is often not achieved. (Gidado 1996, Ballard, Glenn 2012).

2.1.3 Organisation

Stakeholders

Stakeholders in construction sector are more complex than in most other industries (Yang et al. 2009). Feige et al. (Feige et al. 2011) explains this by the complexity of building projects and also by their great impact on the environment and the economy. Freeman (1984) defines the word stakeholder: "any group or individual who can affect or is affected by the achievement of the organisation's objectives". The main stakeholders and their interests during the project life cycle phases are illustrated in table 1. As we can see, there are various stakeholders with

their own interests in different phases of construction projects. According to Freeman the stakeholders can be divided into three groups: internal (mainly strategic) and external (mainly normative stakeholders) and the public authorities (a strategic and a normative role) (Freeman 1984).

Table 1 Stakeholders interests in construction projects (Freeman 1984)

	Key stakeholders	Life cycle phase	Main concerns
Internal, strategic stakeholders	Investor	Project development phase/ concept/design phase	Return of investment; economic feasibility; corporate social responsibility; regulation; personal beliefs; company image
	Manufacturer/supplier	Construction phase/revitalization phase/modernization phase/ deconstruction phase	Energy supply; availability of natural resources; economic feasibility; cost-efficiency; workforce; corporate social responsibility; regulation; personal beliefs; company image
	Banks/financial Institutions	Project development phase/idea/ capital	Return of investment; company image
	Contractors	Construction phase/revitalization phase/modernization phase/ deconstruction phase	Materials and energy supply; economic feasibility; cost-efficiency; workforce; corporate social responsibility; regulation; personal beliefs; company image
	Planners/designers	Project development phase/ concept/design phase/ construction phase	Knowledge; creative and efficient application of technologies; cost-efficiency; corporate social responsibility; regulation; personal beliefs; company image
	End user/owner	Operation phase/maintenance phase	Well-being; economic feasibility; lifestyle; personal beliefs; company image
Both internal and external stakeholder	Public authorities	All	Regulations and control; well-being
External, normative stakeholders	Non-governmental organizations (NGOs) and civil society	All	Social equity; access to information; well-being
	Research and education	All	Technology and knowledge
	Media	All	Democratic share of information
	Environment	All	Permanent degradation
	Future generations	All	Social equity, well-being

Moreover, in figure 3 Vrihoef and Ridder (2007) illustrate the supply system complexity through the construction stakeholder's relations. The figure underlines the complexity of stakeholder's relationships and interests. In every project all these groups interests must be taken into account, so it is a not surprise that almost every project is unique.

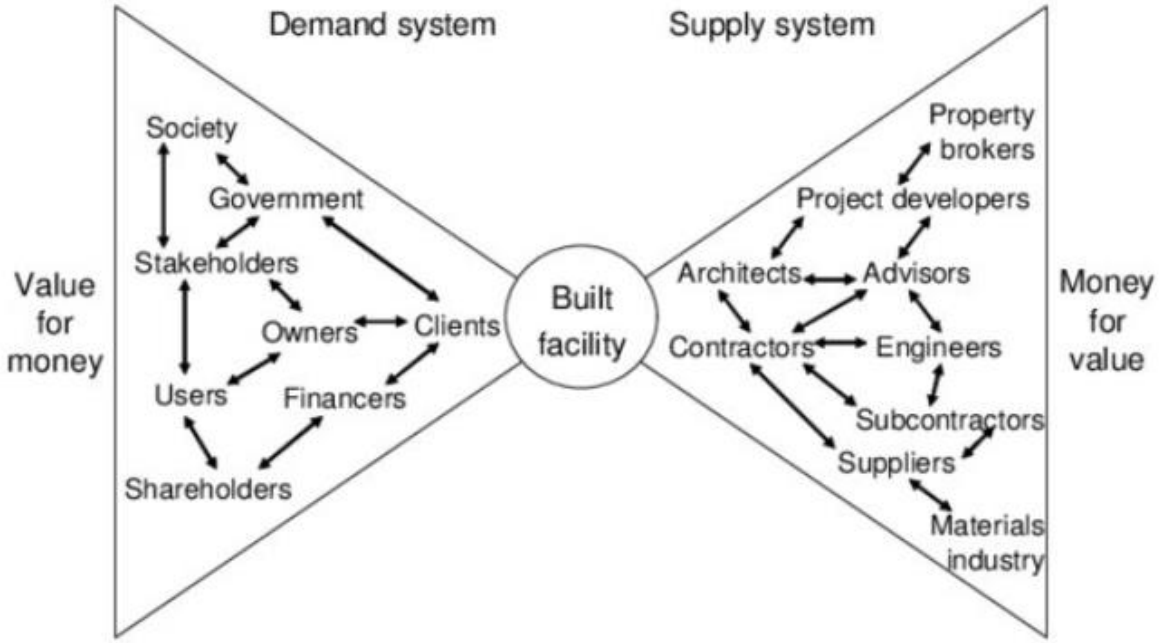


Figure 3 complexity of demand and supply system (Vrihoef and Ridder, 2007)

Labour-intensive and fragmented industry

Compared to other industries the construction production is not automatised and still uses a great amount of hand work. Therefore, the skill level of workers has a great impact on how projects are organised and carried out. (International Labour Organization 2001) The residential construction industry entry barriers are very low which causes highly fragmented company distribution in the sector (Clarke, Winch 2006). For instance, according to the statistics in Finland, micro-sized companies with less than 10 workers represent 91,9 % of all companies in the sector; small- and middle-sized companies 7,9 %. This means that just around 0,2 % of companies are large enterprises (Ahonen et al. 2020). Those numbers show the dominance of small companies in the industry. The small companies' dominance in the industry also indicates that most of the companies may not have resources to invest in productivity improvement initiatives.

Discontinuity across projects

Another great challenge in the project-based production is the discontinuity of the work. Contractor companies form teams and supply chains for each single project and when the project is completed, the teams and supply chains will be dissolved. Lack of continuity has an impact to weak integration in supply chains and strategic collaborations. Moreover, the learning curve is low when the projects are unique and cooperation with suppliers and sub-contractors is often rather short-term as opposed to having long-term objectives (Wood et al. 2013, Vrijhoef, Koskela 2005)

Project delivery systems

Stakeholders work together with different kinds of settings that are called project delivery systems. These delivery systems are different types of contracts that describe the different roles and responsibilities in the project. Organisations are shaped by the scope of a contract type and by duties. (Ballard, G. 2008).

The main project delivery systems in residential construction are as follows:

> Design-bid-build: traditional contract type used in the construction industry, called also conventional project delivery. The design and the building phases are contractually separated which means that a main contractor is not responsible for the design but just carry out the building phase. In this delivery system one phase is completed before the next phase is begun without overlap. (The american institute of Archtiects 2009, Kubba 2017).
>
> Design-build: The owner contracts directly with one entity (Design-Builder) who is responsible of the whole process from the design phase to the building phase. A Design-Builder role can be: 1. A Developer or Single Purpose Entity (design and construction in one company) 2. An Architect-led organisation 3. A Contractor-led organisation (usually in most cases). (The american institute of Archtiects 2009, Kubba 2017)
>
> Integrated Project Delivery: "Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximise efficiency through all phases of design, fabrication, and construction". (The American Institute of Architects 2007).

Why are there so many project delivery systems in the residential construction? There are many types of projects, and cooperation between major stakeholders depends of the project attributes, for instance: project size, scope, maturity of the project data and time schedule. Moreover, attributes such as competences of stakeholders and preferences of client have a great impact on the selection of the delivery system. Therefore, one delivery system is difficult to apply in all projects. (Ballard 2008, Baccarini 1996, Wood et al. 2013)

The characteristics show that there are many factors that increase complexity in the residential construction industry. Some of these attributes such as high-level impact to society or immobility of building are often unchangeable factors. Understanding the main issues in the residential construction and its supply chains is essential to improve the industry. According to various scholars, the fragmentation of industry, the one-off product including temporary organisations, and the site production are the main problematic factors that obstruct

improvements in residential construction supply chains (Vrijhoef, Koskela 2005, Koskela 2000).

2.2 Characteristics of industrialised construction

Numerous attempts have been made to tackle these various problems in the construction industry. The industrialised construction (IC), has raised attention in literature and in construction companies due to its economic benefits. The idea of IC refers to the production system that utilises prefabricated systems, modules and standardised components which are produced in a stable factory environment and transported to the construction site for assembly In turn, the term "industralisation" refers to investments in equipment, facilities, and technologies with intent to change the business towards industrialised construction. (Razkenari et al. 2018). The potential benefits from IC are diverse. For instance, with the off-site manufacturing the quality of building process can increase (Zabihi et al. 2013). On the other hand, IC is expected to improve the productivity, reduce waste and project lead time, and overall lower the environmental impact with higher sustainability performance (Chen et al. 2010). Similarly, as the traditional residential construction had its own characteristics explained in chapter 2.1, the industrialised production has its own characteristics. Table 2 below illustrates the characteristics of industrialised production and demands on industrialised construction.

Table 2 Characteristics of industrial production and parallels to construction production (Girmscheid 2005)

Characteristics of industrial production	Demands on industrialized construction
Centralized production	Pre-fabrication of components at the factory
Mass production / increasingly variable production	Development of variable basic types
Production based in standardized solutions and manufacture of variations	Standardization of components but still maintaining flexibility of design
Specialization	Focus in specific market segments
Integration of planning, production and marketing	Interaction of building design, production planning, production / construction
Optimized processes and organization	Optimization of the planning and production processes in terms of automation and mechanization

Building element's prefabrication has started from the mid nineteenth century but still today a great amount of building happens at the building site. A building's uniqueness can be seen preventing the standardisation of components and the developing of variable basic types of buildings. In addition, how to maintain enough flexibility to address markets and people's demands is another great challenge. Girmcheid (2005) also underlines the interaction of the

building design, production planning and construction processes as an important objective. Currently, in many cases construction drawings are not designed with respect to efficient production practises. Although, the design and build projects are addressing this problem in some extent (The American Institute of Architects 2007).

However, the interaction is often highly dependent on individual persons and fluctuates between different projects. Thus, the two last fields in the table 2 "*Interaction of building design, production planning, production / construction*" and "*optimization of the planning and production processes in terms of automatization and mechanization*" could mean in practise to development of a design platform. A design platform could reduce the fluctuation between projects and enable utilisation of standardised components. The industrialisation of construction requires actions in many fields, but design platforms could play a one role in transformation process.

Possible solution towards industrialised construction

A promising approach to standardise building components and processes may be to utilise modularity and a product design platform. In many manufacturing industries, the product design platforms are successfully used to decrease complexity which has led to productivity and flexibility advantages. One example is the car industry which has the ability to provide a high level of customisation without compromising quality, lead times and cost (Parry, Graves 2008). Baldwin and Clark (2000) describe three different characteristics of a product design platform as:

- a modular architecture
- interfaces
- standards

The common approach to develop design platforms is to develop tools, methods and algorithms which support the physical products (Yigit et al. 2002). In addition, Robertson and Ulrich (1998) argue that product platforms meaning can be seen in broader extend than physical structure of product, they see product platforms more as a collection of assets, that are common and can be used for a set of products (Robertson, Ulrich 1998). Of course, the successful implementations in other industries does not mean automatically that same approach is suitable to construction industry. Therefore, the approach must be contextualised and modularity has to be reviewed from construction perspective. The following chapters focus on modularity theory and applications in ship building industry as well as in construction industry.

3 MODULARITY

Modularity is not a new concept. Over the years its meaning has been changed in different contexts. Modularity is becoming more and more popular as a concept in research and in several industries' strategies, including residential construction. The purpose of this chapter is to define the concept and describe its meaning in different domains. I will also discuss modularity strategies in two closely related industries; the residential construction and the ship building industry.

3.1 Modularity in different domains

The word module is derived from the Latin word "modulus" which was used as a measurement unit in classical architecture (etyonline 2020). The term "modularity" describes the degree to which given complex system can be broken apart into subunits (modules) which can be built and recombined in various ways (Simon 1962). Ulrich and Tung (1991) define modularity in their article "*Fundamentals of Product modularity*" in terms of two attributes of product design: "1) similarity between the physical and functional architecture of the design and 2) minimisation of incidental interactions among physical components" (Ulrich, Tung 1991). Moreover, Ulrich states in his further research that a modular product or sub-assembly has "a one-to-one mapping from functional elements in the function structure to the physical components of the product" (Ulrich 1995). Baldwin and Clark argue that each module in a modular system communicates and interacts with the others through standardised interfaces that allow modules decoupling (Baldwin, C. Y., Clark 1997). As in Ulrich and Tung's (1991) work, this definition only covers the functional aspects of a product, ignoring all other domains — such as management, process and organisation. Again, according to several other scholars the research in modularity is focused on the product aspect (Campagnolo, Camuffo 2010, Fixson 2006). However, it is important to view modularity from a broader perspective. From a managerial approach, product, process and organisational elements should be treated equally (Campagnolo, Camuffo 2010). Moreover, different stakeholder's interests should be taken into account (Baldwin, Carliss, Clark 2000) . The following chapter reviews modularity in detail in different domains.

Product architecture

Product architecture can be integral or modular. An integral product architecture contains components that have many functions, are in close relationship with each other and are higly synchronised. (Voordijk et al. 2006) Modular product architecture refers to the way in which product is divided into modules, and how modules' functions, actions and interfaces are closely mapped to create a complete product. Unlike an integral product architecture, a modular architecture consists of independent sub-assemblies that are connected to each other with standardised interfaces. (Ulrich 1995) According Voordijk et al. (2006) two major factors describe modular product architecture: independence of components and interfaces. According

to Ulrich (1995), product interfaces can be classified with three different categories; slot architecture, bus architecture and sectional architecture (Figure 4).

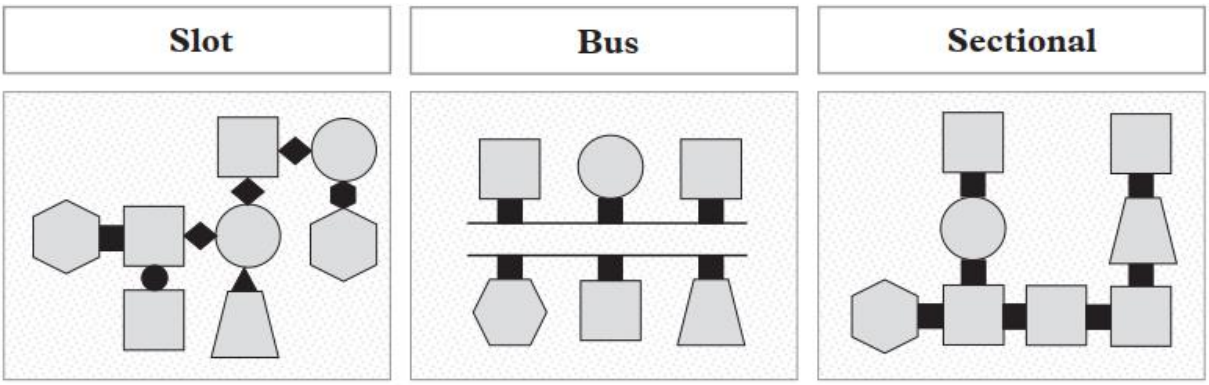


Figure 4 Slot, bus and sectional interface types (Peltokorpi et al. 2018)

The differences between interface types are dependent on the way the interactions are organised. Ulrich (1995) explains these differences as follows:

> **Slot.** Each of the interfaces among the components is different compared to others; this means that the various components in the product cannot be interchanged. Example: in construction wall elements among each other (Jensen, et al. 2015).
>
> **Bus.** All components are connected to a common bus-component with the same type of interface. This type allows changes of the places of components, and therefore offers more freedom than the slot type. Example: In construction a foundation where different types of wall elements are installed (Jensen, et al. 2015).
>
> **Sectional.** All interfaces are connected to each other with same kind of interface without a single common component to which other components attach. This enables placement of components in any order. Example: prefabricated volumetric modules in construction (Jensen, et al. 2015).

One modular system can consist of several different categories of interfaces, and one category can comprise various interface designs (Voordijk et al. 2006). Standardisation of interfaces offers several different benefits. It reduces complexity and makes it easier to manage product design and manufacturing, as modules can be changed and developed independently keeping the interface unchangeable. Because of this, the modular product design should focus on clear stardardised interfaces between modules. (Bertelsen, Koskela 2005).

Modular product architecture should also have respect for different stakeholder's interests. To make it easier to understand different parties' interests in the modularity of product Baldwin

and Clark (2000) have presented classification for the interests. They differentiate Modularity-in-Production (MIP) from Modularity-in-Design (MID) and Modularity-in-Use (MIU). If a product is designed with emphasis on MIP the product may not satisfy the other approaches (Baldwin, Clark 2000). The same result may arise if the product is designed with respect to MID without taking into account the production and the user aspect. According to Bekdik (2017) modularity loses its benefits if products are designed parallel without taking into account all three interests. If MIP is not respected in the design the component may not be suitable to production, where economics of scale is an important factor. On the other hand, logical modules for production may not be favourable for users. (Bekdik 2017).

Production system modularity

As product modularity referred to "modularity-in-design", the production system modularity corresponds to "modularity-in-production" and defines how the product is produced (Vickery et al. 2015) . Campagnolo and Camuffo (2010) argue that modular product should also have an underlying, predefined modular process or a modular production system. The idea is that the modular production system is mirrored by the modular product, as different tasks are grouped around modules of the product. Campagnolo and Camuffo (2010) present two ways to deal with this idea. The first approach is outsourcing activities and the correlation between outsourcing and the modularity of the product. Campagnolo and Camuffo (2010) call this relationship between product modularity and outsourcing strategies *Modularity and Task Management*. By outsourcing activities an organisation can focus on their core activities and creating more immediate value (Bekdik 2017). The second approach is the *Modularity and Network* perspective which covers the organaisational boundaries and inter-firm coordination.

According to Campagnalo and Camuffo (2010) there are several researchers who have studied the connection between outsourcing activities and product architecture modularity and whether there is any causal connection to any direction. Sako (2003) and Campagnalo and Camuffo (2010) explain how outsourcing of activities can be the way to achieve modular product architecture simultaneously with an outsourcing process. Sako (2003) drafts three major paths how an organisation can move from manufacturing integral products towards outsourcing product modules — acd, abd, ad — presented in figure 5.

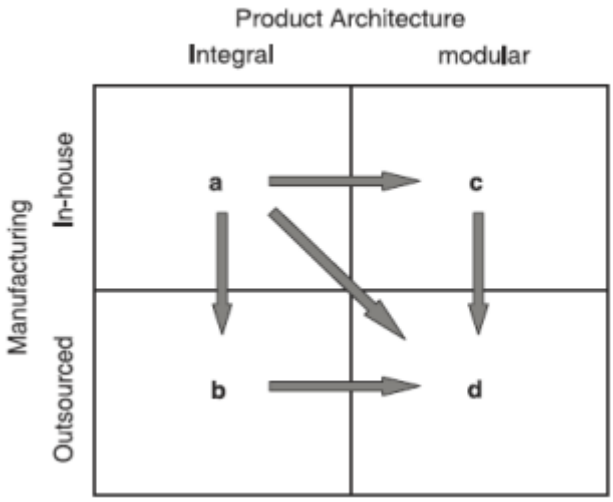


Figure 5 Paths towards module outsourcing (Sako, 2003)

In the first path (acd), the company first modularises their product and then starts moving towards outsourcing of the module production. In the second option (abd) the company starts to outsource some of the product components before designing the modular architecture. This path appears more commonly in mature industries where many firms have already outsourced many of their activities to achieve efficiency in manufacturing and assembly. In the third path (ad) the company simultaneously produces modularitisation of the product and outsourcing. (Sako 2003, Campagnolo, Camuffo 2010) What is the most favorable path to follow? The research shows that the right outsourcing strategy is highly dependent on various conditions, such as the specific attributes of the product, firm strategy, industry maturity, firm capabilities and the modularisation task itself (Campagnolo, Camuffo 2010). Therefore, there is no simple answer for which path is right. According to Campagnolo and Camuffo (2010) different paths can lead to the different final result in modular architecture, even in the same product. This can be in terms of module boundaries and interfaces. For instance, a laptop produced in-house would look different than if the production had been outsourced. Therefore, companies should first think what is important for them, in terms of modular boundaries and interfaces in the final product before going towards outsourcing or giving freedom to suppliers to do their own modules. (Campagnolo, Camuffo 2010).

The research and case studies concerning the construction industry argue that, in addition to the above-mentioned architecture, modular boundaries and interfaces, two other process dimensions need to be considered as well: time and space (Voordijk et al. 2006). According to them, the construction process and its modularisation are dependent on the geographical conditions and capabilities of the firms involved and, in addition, on the changing requirements of the product in different phases: production, transportation, and final usage alternatives (Voordijk et al. 2006).

The second perspective *Modularity and Networks* deals with organisational boundaries and inter-firm coordination. Baldwin and Clark (2000) indicates that the product design modularity has effects on firm boundaries and industry structure, but their significance is still disputed. According to Campagnolo and Camuffo (2010), several scholars argue that there is a "new" common model of industrial organisation, where major players focus on market control, market penetration and market defense, while manufacturing is left to subcontractors. Sturgeon (2002) calls this type of industry M*odular Production Network*, a concept that has been used to describe the contract manufacturing in the US electronics industry. Furthermore, Sturgeon (2002) states that companies identify the breaking points within the value chain where product or modules can be highly formalised and easily transferred. Studies show that product and production systems' modularisation can be one of the major forces driving companies towards disintegration and a horizontal industry structure. In addition, research reveals that institutional forces also play a great role in shaping the evolution of the production system. (Campagnolo, Camuffo 2010) For instance, in the residential construction industry institutional contractees have lot of power to decide, if they want modular products or integral products, and thus their impact on production systems has to be considered.

Organisation and supply chain modularity

Ulrich (1995) states that "highly modular designs allow firms to divide their development and production organisations into specialised groups with a narrow focus". This definition refers to modular organisation. Furthermore, this structure may also extend to the supplier network of the company, when the concept is called modular supply chain (Ulrich 1995, Voordijk et al. 2006). Ulrich (1995) explains that if the function of a component is possible to specify precisely and the interface between the component and the rest of the product is completely characterised, the design and production of that component is then possible to outsource to a separate entity or in other words to a firm. The challenge is to design these organisational boundaries and interfaces to mirror properly the modular product and the production system architecture. According to Campagnolo and Camuffo (2010), modular organisations and supply chains have benefits, such as reduced need for communication of hidden information, as the all knowledge within the module does not need to be shared. They also state that a modular organisation operates like a network rather than a hierarchy. This network structure has an advantage in terms of fast decision making and manufacturing speed (Bekdik 2017). One potential negative aspect of modular product architecture is the risk of creating organisational barriers to architectural innovation (Ulrich 1995). The other risk is that modular organisational units become too independent and thus alienated from each other (Bekdik 2017). However, this risk can be reduced by investing in supply chain management.

3.2 Modularisation in the ship building industry

Like the residential construction industry's characteristics mentioned in chapter 2.1, the ship building has been a traditionally highly volatile project-based industry which produces one-of-

a kind products that have an integral architecture (Segerstedt, Olofsson 2010, Erikstad 2009). Moreover, the ship building industry has other similar attributes with residential construction, such as complexity and the size of a product. Moreover, ships also have cabins, which are similar with apartments in buildings. As in various other manufacturing industries, such as computer and automotive manufacturing, ship building industry has lately moved towards modular production (Erikstad 2009). According to literature, the modularisation in ship building industry has achieved some good results in project lead time and productivity. For these reasons, understanding modularisation in ship building can be useful when studying modularisation of residential construction.

This section focuses on modularisation strategies in specific phases of the ship building process. Erikstadt (2009), presents in his article important modularisation research projects in Norwegian ship building industry. Erikstadt's (2009) findings can be divided into three categories; modularisation in tendering process, modularisation in ship designing and modularisation of ship production. In figure 6 the key concepts in the modularisaton of ship building and their relations are illustrated. In short, modules are building blocks for a product platform. They also offer building elements in a configuration-based-design system, and customised products can be generated by scaling and combining standarised modules towards specific end user demands, i.e. "mass customisation". (Erikstad 2009) Perhaps one missing aspect in the Erikstad's model (figure 6) and in his studies in general is that does not describe clearly how the production system is linked with the modular ship design.

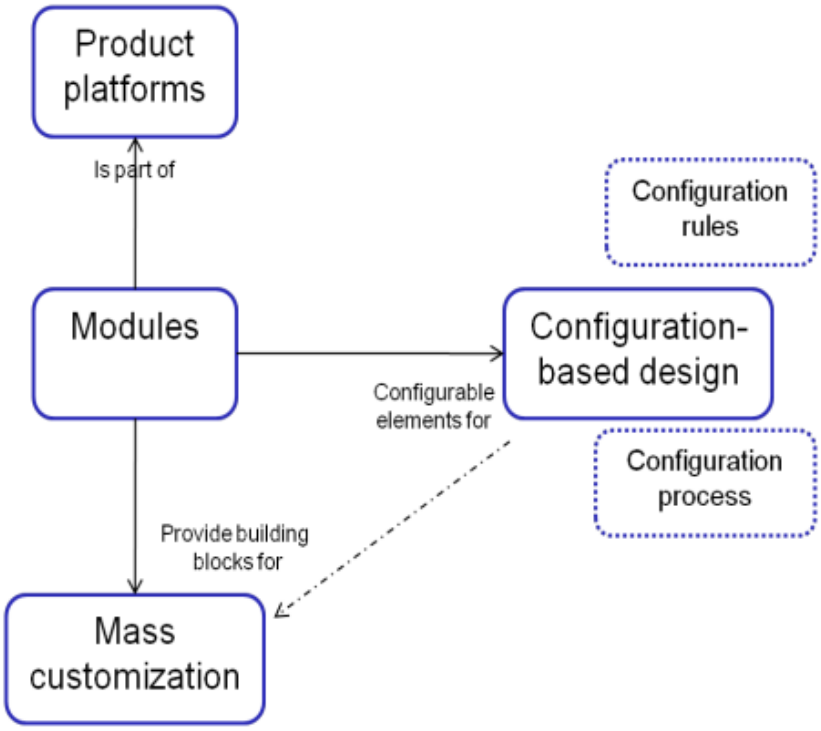


Figure 6 Core concepts related to modularity (Erikstad 2009)

Modularity in the design and tendering process

According to Norwegian professor Stein Olev Erikstadt, one of the forerunners in the modular ship designing has been Ulstein Design. Ulstein Design has developed a product platform that they use to configure individual vessels based on customer demands. Ulstein's platform-based vessel designs are illustrated below in figure 7. The other good example of modular ship architecture is the modular cruise ship manufacturing, presented in figure 8, where cruisers are designed by configuring predesigned modules together. (Erikstad 2019).

Figure 7 Platform based vessel designs (Ulstein Design)

Figure 8 Modular cabins in a cruise ship (Jogeva 2014)

A platform can be defined in this context as "*a structured, coherent collection of resources, including systems and template hierarchies, textual components, variants, rules and interface definitions, from which a range of customised product definitions can be derived*" (Erikstad 2019). In turn, modularisation and modules can be seen as building blocks of product platforms. The idea of this platform-based design is to have an early specification phase that is as consistent as possible with further engineering and with the end production. (Erikstad 2009).

Some of the possible benefits of modular product architecture are the short lead time and fast configuration combined with customisation. According to Erikstadt (2009), one of the key competitive factors for shipyards is the ability to answer to the tender invitation efficiently with a high-quality tender which meets the demands of the customer. Traditionally the tendering process in each individual project generates a great amount of specification documents and drawings. This approach is time consuming and sensitive to mistakes which can lead to reduced competitivity with respect to winning the bid. One way to develop the tender process based on modularisation principles is to use a module-oriented platform approach and a configuration system. (Erikstad 2009) . Figure 8 represents a vessel configuration based on platform and modules, and figure 9 illustrates possible benefits that can be achieved by the platform-based approach.

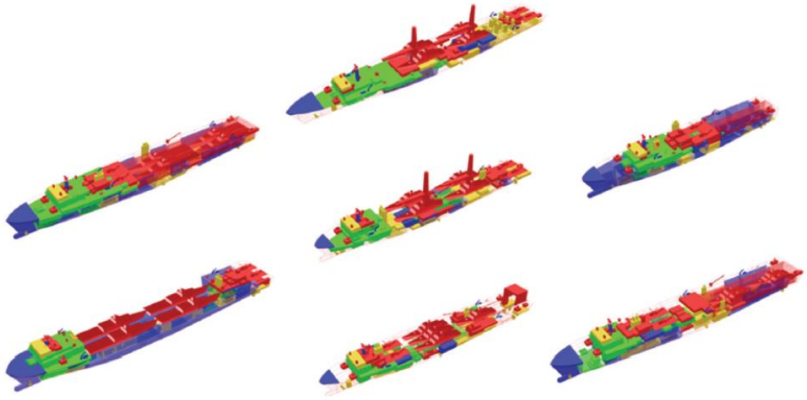


Figure 9 Configuration of a vessel from modules (Andrews 2011)

Design configuration system can be defined as: "*A (software) system that enables a structured definition of a valid design solution from a given set of customer requirements, by applying pre-defined rules and templates to select, scale and synthesize a collection of modules*" (Brathaug et al. 2008).

Configuration can be described as: "*a particular class of routine design, in which the major design elements – modules – are known, and that these can be combined into a solution that meets the customer requirements without involving the development of new solution elements*" (Erikstad 2019)

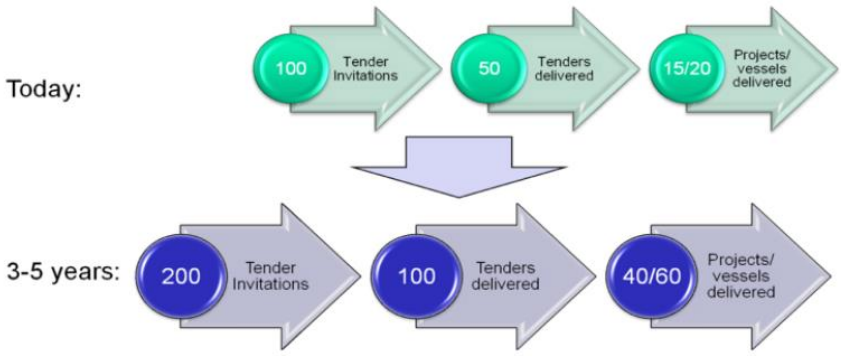


Figure 10 A modular design platform's possible improvements in the efficiency and quality of the tendering process, (Erikstad 2009)

According to Erikstadt (2009), the main difference is that while traditional approach focuses on developing individual projects, the platform approach focuses on two aspects:

- *Product platform development*, including all activities concerning establishment and maintenance of the platform. In this platform the individual projects will be generated in different families of products.

- *Product platform exploitation,* including the specified customer delivery projects based on the configuration and further customer specific refinements.

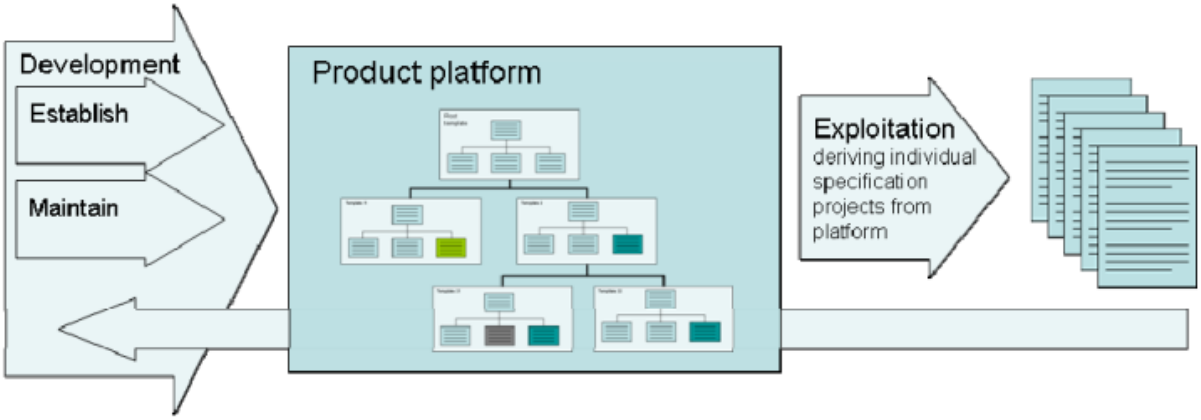


Figure 11 Platform's development and exploitation process

Creating of a platform and maintaining it requires resources and the important question is how to allocate resources between development and exploitation (Erikstad 2009). To answer this question, Erikstadt argues: "*Allocating more resources for the modularisation and platform development process is expected to reduce the effort and improve the quality for each specification project*" (Erikstad 2009). Therefore, it makes sense to continue spending resources in platform development as long the net productivity and quality in the exploitation phase is positive. It is also important to identify a) what parts of the portfolio are the most cost-efficient to invest resources and develop solid platform and b) where it may be better to develop a few flexible and easy to configure general platforms. This matter can be conducted by observing old projects and clustering them to different product groups. (Erikstad 2009).

Modularity in ship production supply chain

The shift towards platform approach and modular product architecture also has considerable impact in supply chain. A modular ship architecture with well-defined interfaces between modules enables outsourcing in larger scale and more flexible global supply chains (Erikstad 2019). By standardising and making interfaces of design "clearer" ship builders aim to have more flexibility to select foreign shipyards with lower production costs (Halse Sep 2014). Production costs can also be reduced without offshoring production to low labour cost countries, because a modular product architecture has enabled reuse of standardised components and a longer production series in component manufacturing. An appropriate level of defined module interfaces also encourages suppliers to invest their components' and modules' development. One good example is the previously mentioned cabin module in figure 8 (Erikstad 2019, Erikstad 2009).

What happens at the market level? In the big picture the major question is to what extent there is a relation between shipyard's modularisation and the supply chain structure. According to

the studies, there are two major impacts on the supply chain structure and power balance. First, there is a shift in control over the ship specification. Traditionally, the shipyard designs and builds ships according customers specifications. With a modular and product platform-based design this power balance has been shifted towards shipyard, and a customer role is to select one set of possible designs generated from a platform. (Erikstad 2009).

3.3 Modularisation in construction

Like the characteristics to residential construction described in chapter 2, the industry today produces mostly complex and unique products with temporary organisations, involving multiple stakeholders and processes. These characteristics increase construction complexity, which in turn causes the low productivity in the industry. A modularisation has been lately perceived one as one potential approach to deal with productivity problem in the residential construction industry. In the following section the modularity of residential construction industry is outlined, and different classifications and approaches are presented.

A clarification of terms in this industry is essential. In literature terms modularity, modularisation, prefabrication, pre-assembly and off-site manufacturing are often mixed and their boundaries are ambiguous (Gosling et al. 2016). According to Bekdik (2017), in the construction industry, the implementation of modularity theory has in many cases been restricted to the product level only and is often seen as synonymous with prefabrication, pre-assembly, off-site production and off-site manufacturing. However, modularity should be seen as a broader approach, as described in section 3.2 *Modularity in different domains,* to address productivity problems in the industry. Modularisation can be defined a process that includes all activities needed to shift towards modular building production (Gosling et al. 2016). Modularisation enables use of off-site production methods defined below. Ballard and Arbullu (2004) define prefabrication as the manufacturing that happens outside of the building site in a temporary or in a permanent workshop (Ballard, Glenn, Arbulu 2004). The preassembly refers to joining prefabricated components to construct a building system or a complete building. Off-site manufacturing includes prefabrication and preassembly and refers to production that is performed outside of the building site (Gib 1999).

In his further study Gibb (Gibb 2001) uses different approach to classify off-site production:

- *Component Manufacture and sub-assembly*
  This category comprises raw materials and all small-scale sub-assemblies (e.g. door, windows or furniture)
- *Non-volumetric pre-assembly*
  “Two-dimensional” elements are prefabricated off-site and assembled on-site. (e.g. wall elements, structural slab elements and pipework assemblies such as radiators)
- *Volumetric pre-assembly*

Specific parts of buildings are produced off-site and then assembled on-site. Usually they are installed within independent structural frames. (e.g. pre-assembled building service risers and modular lift shafts)

- *Modular building*
  Modules with high level of completion themselves form a building. Most of the work is conducted in off-site factories and only foundation and finishing works are done on-site. (e.g. modular schools in Finland, modular residential blocks in Denmark)

Voordijk et al. (2006) divide modular solutions in construction into three different categories: (1) modular, (2) integral, and these two combined, (3) hybrid. This classification is useful when different modularisation strategies are discussed in further sections.

Drivers towards modularisation

Major causes for productivity problems in traditional construction supply chain were discussed earlier in chapter 2. These causes were; the fragmentation of industry, the one-off product approach including temporary organisation and the site production. These factors have impact on high complexity of construction industry and in many cases lead to low productivity. A modular architecture is argued to reduce complexity in buildings and in its design phase, because the dependencies between components are decreased. Moreover, this enables components can be independently designed, and manufactured within offsite technologies. (Voordijk et al. 2006) Modular design platforms are argued to address to one-off project approach and then enable the shift towards project-independent business approach (Vrijhoef, Koskela 2005). Modular designing platforms within configuration tools are also argued to address to the growing demands of customisation with low costs (Jensen, et al. 2015, Baldwin, Clark 2000). In addition, scholars such as Ulrich (1995) and later Erickstad (2009) state that modular product platforms can reduce lead time and mistakes in designing and tendering phase, as they use predesigned modules and templates with clearly defined interfaces. Despite the fact that the modular platform approach is broadly studied and successfully implemented in other industries such as computer industry, car industry and to some extent in ship building industry discussed earlier, the applications in residential construction industry are still quite scarce (Jansson et al. 2014).

The shift towards a more project-independent business enables long term-thinking in supply chain management and its development (Campagnolo, Camuffo 2010, Vrijhoef, Koskela 2005). Increased stability within longer production series makes it possible to deepen co-operation between suppliers, which can have positive outcomes such as increased innovation investments and decreased unit costs (Voordijk et al. 2006). Modular building architecture and clear module interfaces can pave the way towards modular production networks which are vertically disintegrated and need less intense interaction than the traditional supply chain (Voordijk et al. 2006). According to Voordijk et al. (2006) this enables construction firms to shift from “inward looking” in sourcing to “outward looking”, in other words, firms can outsource their activities in a geographically less restricted way and thus obtain various benefits.

Modularisation strategies in construction

Without clear objectives and a good plan construction firms are more likely to fail in their modularisation intentions. In construction, modularisation can mean several levels of modularity and cover various methods to utilise sub-components, components, non- volumetric and volumetric elements in designing and producing mass-customised buildings (Peltokorpi et al. 2018). Moreover, the process and the supply chain aspect should also pay attention while modularising product architecture (Voordijk et al. 2006). Consequently, a modularisation strategy's job is to clarify the objectives of modular production system and define the way modularity should be exploited in these different domains of modularity (Peltokorpi et al. 2018).

> "*product modularity must be guided by clearly stated goals, which in turn affect product modularity definition and how to modularise*" (Campagnolo, Camuffo 2010).

Peltokorpi with his colleagues have recently worked to study modularisation strategies in the construction industry. Their theoretical framework is created to categorise modularisation strategies according to their objectives in building investments illustrated below in figure 13. While previous research emphasises that the modularisation strives to gain benefits in the building phase, mostly related to cost efficiency, quality or schedule, their framework outlines that there can be other objectives in different phases of a project's life cycle. (Peltokorpi et al. 2018)

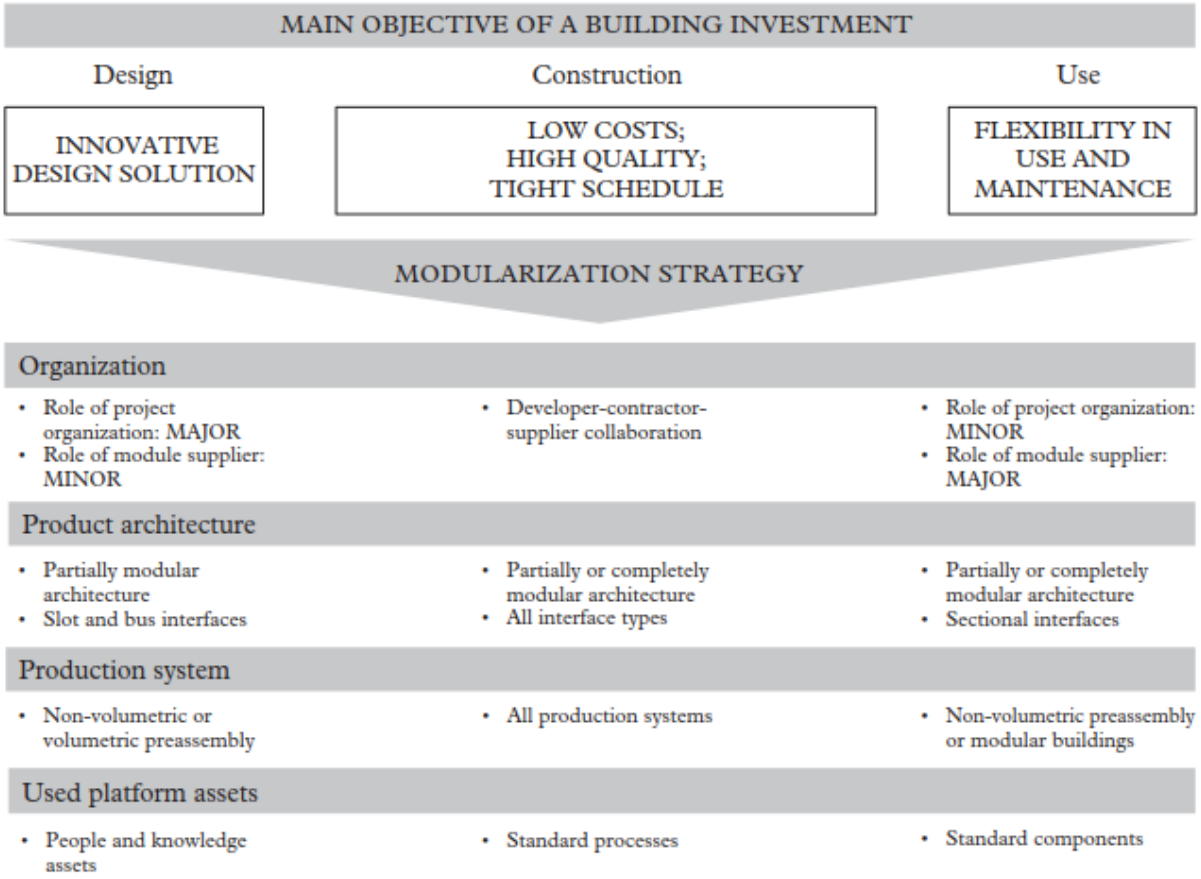


Figure 12 Petltokorpi's et al. (2018) theoretical framework for classifying modularisation strategies according to the main objectives of building investments

The building investment's major objective can be "*innovative design*" where project organisation involving the project owner, designers and contractors, plays a big in role defining the design of crucial components and modules. The component supplier's role is rather to prefabricate and deliver the module, as its natural incentive is to use more scalable and mature design solution (Hofman et al. 2009, Peltokorpi et al. 2018). This kind of strategy can be suitable for one-off kinds of projects such as hospitals and commercial buildings. The other extreme on the left of figure 13, is when the component or module supplier has given greater autonomy to use their standard interfaces and components as platform assets that makes economics of scale during the production possible but in addition in post-construction services. The third strategy that emphasises improved performance during the construction phase can be positioned in the middle between these two extremes, as this strategy is often based on standard offsite production processes of module suppliers but not always on fully standardised components or interfaces. In this strategy the project organisation role can be greater than when focusing on flexibility in use and in maintenance.

Peltokorpi et al. (2018) summarise these three different strategies as follows:

> Strategy 1: "*If modularization aims at innovative design solutions in repetitive structures and spaces, a project organization-driven strategy to utilize the modularization knowledge of project stakeholders, such as designers and contractors, should be adopted.*"
>
> Strategy 2. "*If modularization aims at improving the cost, quality and/or schedule performance of the project phase without specific targets for innovativeness or the post-construction phase, a prefabrication- and preassembly-driven strategy to utilize standard processes should be adopted*."
>
> Strategy 3: "*If modularization aims at flexibility in the use and maintenance of a building, a module supplier-driven strategy to utilize a supplier's standard components and interfaces should be adopted.*"

The discussed strategy classification is of course simplified and in reality, a modularisation strategy in a single construction project can have various objectives. According to Peltokorpi et al. (2018), the objectives may vary between subsystems or spaces in the same building. Therefore, several production strategies in a single project should be adopted. This, however, can make project management more complex and underlines the importance of defining the boundaries and interfaces between building systems clearly. Peltokorpi et al. (2018) argue that their framework can be used when only considering a single sub-system or one part of the whole building.

This framework may be useful and bring more understanding on how to match a suitable modularisation strategy with the construction project objectives but if we want to utilise it, in the certain field of industry such as residential construction, it should be developed. In addition, Peltokorpi et al. (2018) do not recognise *sustainability* as one major modularisation objective. Recently the sustainability has risen to one of the major topics in business and education. In the future sustainability can be the one of the major competitive factors and therefore it should be adopted to modularisation strategies.

4 SUMMARY OF LITERARY REVIEW

The literature review focused on three themes; characteristics of residential construction, demands of industrialised construction, and modularisation in different contexts. By reviewing the characteristics of the residential construction, the aim was to gain overall understanding about the fundamentals in the operating environment and how supply chains are traditionally organised and in turn what are the characteristic for industrialised construction. The review in modularity theory first in general and later in different contexts, enabled to get knowledge and tools how modularity and modular design platforms could address to major problems in traditional residential construction productivity.

In chapter 2 the characteristics were reviewed from three different aspects: product, process and from organisation aspect. Again, the product aspect findings can be divided to three different group. First is the immobility, buildings are slaves of their location which can mean different soil conditions and other environmental challenges which increases complexity. This is one major factor that separates the housing production from many manufacturing industries. Secondly, buildings have a relatively very long lifecycle and a high-level impact to environment and society. Therefore, regulations concerning building projects are strict and controlled by authorities. Thirdly, almost every building project is unique because of complex regulations and the design process almost always starts from the beginning.

The second perspective focused on the characteristics on construction process. Construction projects last often long time and a single residential construction project duration can often be many years. This sets difficulties to start and carry out projects without time delays. For, instance customers financial situation can fluctuate and building permit processes may have delays. In addition, even one individual person can postpone project start for years due the individual right of appeal. Also, a political situation may change during the project timeline and affect to the project. The characteristic for a construction project is also the amount of work tasks with a great number of interfaces which are executed simultaneously in restricted area and in fluctuating weather conditions.

From the organisation perspective there are several characteristics which increases complexity in the residential construction. First, the stakeholder networks tend to be very complex in the industry. Second organisational factor is the very fragmented supplier and subcontractor field. In addition, there are various project delivery systems which also sets different fundamentals to every project and project organisation. Finally, project-based industry supply chains and project organisations change often and affect discontinuity across projects.

After the traditional construction characteristics, the chapter 2 pointed out the characteristics in idustrialised production and demands for industrialised construction. Many aspects such as pre-fabrication of components, standardisation of components and consistent design and production processess need to be developed and considered in this transition process towards industrialised

construction. Moreover, automation and digitalisation of the planning and production processes play a significant role. Finally, the shift from project-based thinking towards project-independent thinking is essential to achieve benefits with industrialisation.

Literature suggest that modularity should be reviewed in three different domains; product, process and organisation. The product aspect deals with different types of a modular product architecture and explains how standardised interfaces reduces complexity. Moreover, the product architecture aspect should cover various interests (modularity-in-design, modularity-in-production, modularity-in-use) in different phases of production. Modularity loses its benefits if it is designed parallel without considering all of three interests. Moreover, a production system also should mirror products modular architecture. This can mean outsourcing activities due the modular product architecture, or in larger scale, the whole industry starts mirroring the modular structure where major players focus on market control and production is left to subcontractors. Studies also show that modularity is the major force driving companies towards disintegration and horisontal industry structure. The challenge is to design organisational boundaries and interfaces to mirror properly modular product and production system architecture.

The next chapter reviewed modularisation in the ship building industry. The findings show that in Norway, a modular ship architecture, modular design libraries and well-designed interfaces have increased shipyards productivity. Studies also show that a modular ship architecture using standardised modules and clear interfaces can enable longer production series and flexible supply chains. In addition, modular design platforms have enabled a fast tendering process which is a great competitive advantage in ship building industry. In the market level there are signs that a power balance over the product specification has changed due the modularisation.

In the construction industry the implementation of modular theory is often restricted to the product level. However, modularity should be seen in broader extent that it could address to the productivity problems and bring construction towards industrialised activity. Therefore, a process and an organisation aspects should be considered as well. In addition, it is important to understand what modularity means in different project phases and what kind of interest different stakeholders have during each project stage. Modular design platforms are suggested to address to problematic one-off project approach in the industry and enable shift towards project independent business. Again, an increased stability would enable long term thinking in a supply chain management which could mean for instance a deeper partnership with suppliers, a longer production series and increased R&D investments in a supply chain.

Without an appropriate strategy, modularisation possess a great risk to fail. Therefore, studying own competitive advantages, an operating environment, stakeholders and setting clear objectives is essential to gain good results in modularisation projects. A modularisation strategy model based on Peltokorpi’s model is illustrated in the figure 13. This model was chosen to act

as a framework that is later developed to describe what kind of modular construction concept would be suitable for Fira Oy. Moreover, findings in literature show that creating a modular design platform is a complex and long process which have several layers. This development stage of modular design library should be able to estimate and communicate to stakeholders. Therefore, a maturity model is presented in the figure 14 which will be later developed in respect to interview research.

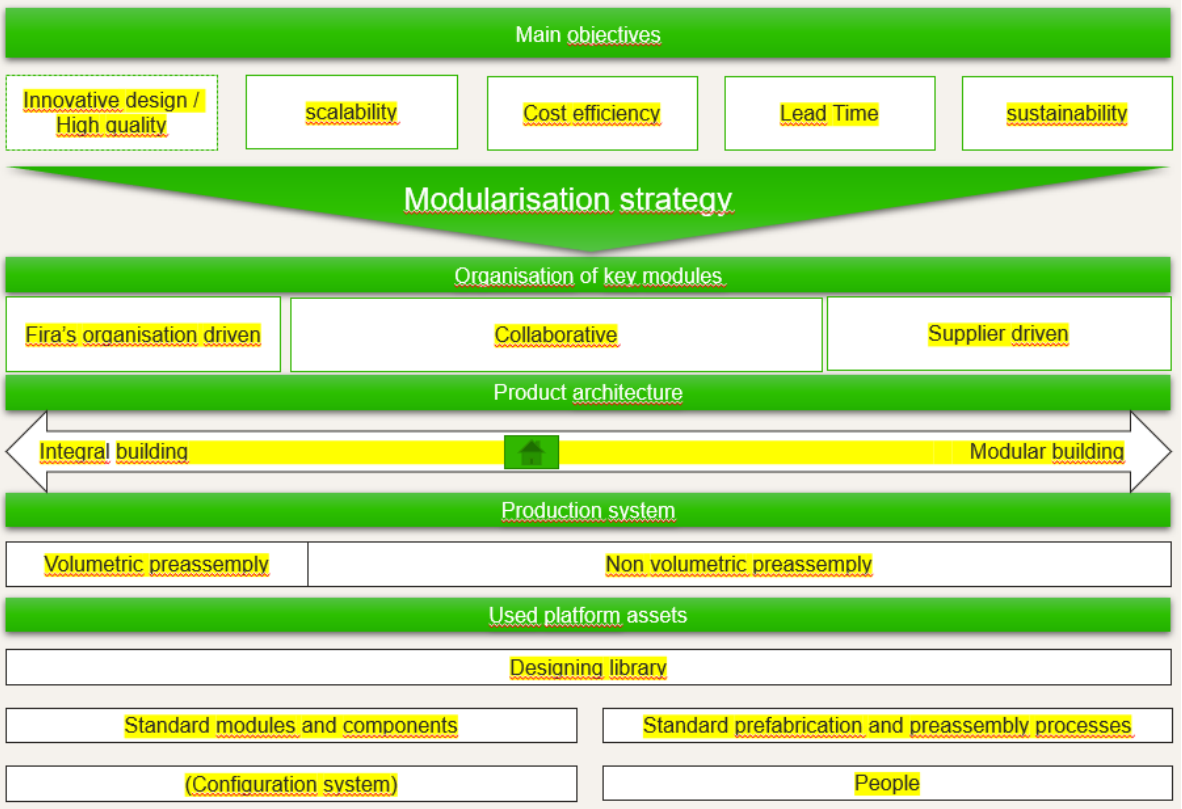


Figure 13 Tentative modularisation startegy model (based on Peltokorpi et al 2018 model)

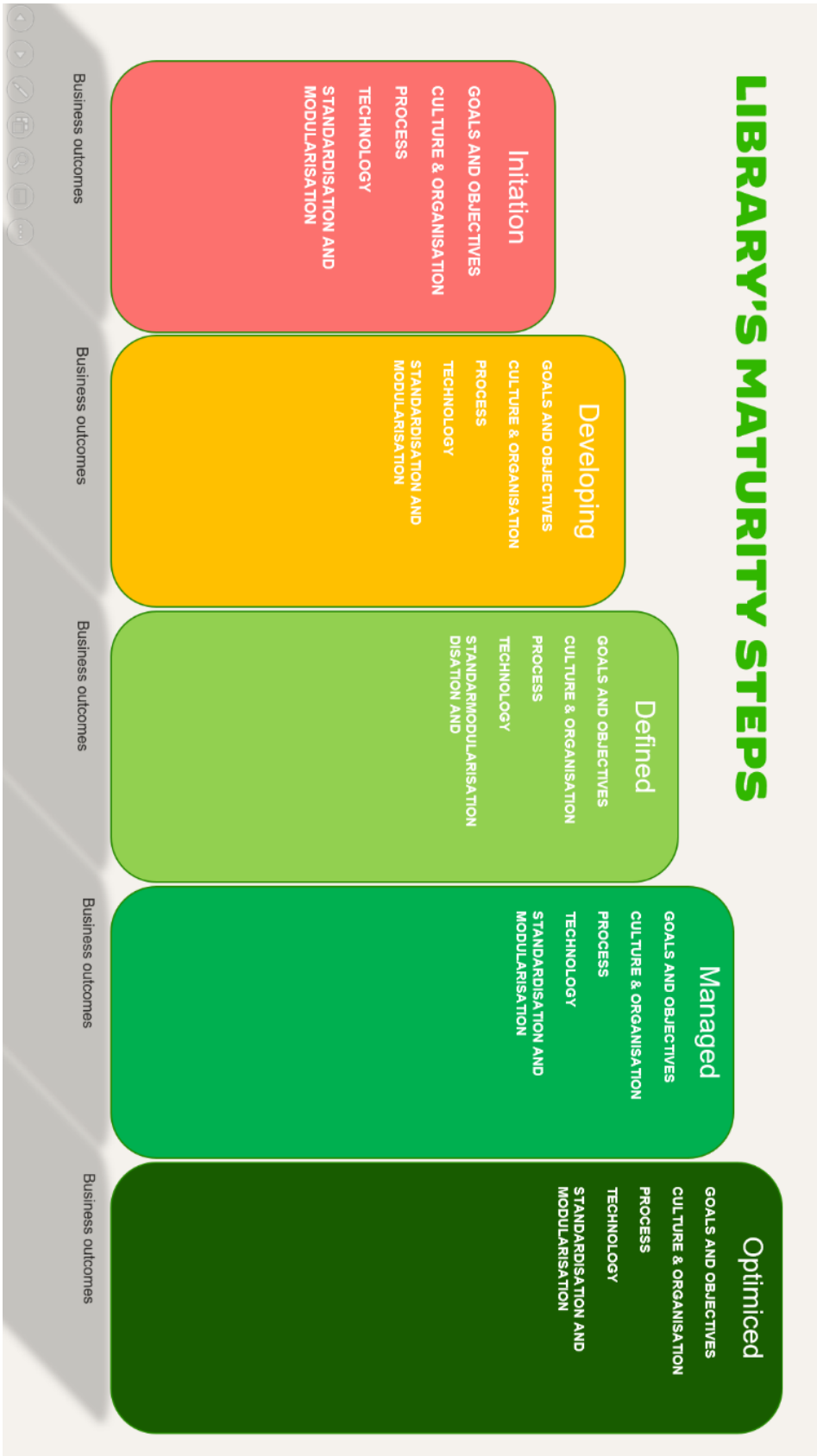


Figure 14 Tentative maturity model

5 REVIEW OF THE CURRENT SITUATION IN THE CASE COMPANY AND IN SHIP BUILDING INDUSTRY

In chapter 2 and 3, the literature concerning characteristics of the construction industry, modularisation strategies and modularisation examples in the ship building industry were explored. Finally, chapter 4 summarised the findings from the literature. In this chapter, the first cycle of design research is reviewed where modularisation strategy model based on literature is modified to be suitable for the case company. First the research approach will be introduced. Secondly, the current status of modularisation in the case company will be reviewed, and the problems in that initiative are identified. After that, the analysis and evaluation of the material will be presented. Finally, the updated strategy model and maturity model will be introduced based on the analysis of the interview material.

5.1 Research approach

5.1.1 The selection of research methods

Identifying the Fira Oy's current modularisation state and material collection for updating the tentative strategy model is conducted by using a qualitative research approach. The material of the current modularisation status and objectives were mostly gathered by semi-structured interviews. Moreover, the existing modularisation thoughts and modular design platform project were mapped out by using participatory observation, in other words by participating in project steering group meetings and other operative meetings. Thirdly, company's existing residential production strategy documents and other documents concerning processes and organisation were analysed. According to Robson (Robson 2002), this type of multimethod approach, also called triangulation, can bring out new aspects and reduce inherent bias of a certain data source and method.

The research approaches can be roughly divided into qualitative and quantitative approaches. According to Hirsjärvi and Hurme (Hirsjärvi, Sirkka, Hurme 1991), the selection of the used method is mainly determined by the problem and the problem layout. As quantitative research is based on analysis of numeric data sets; they are suitable when a study is concerned about some phenomenon intensity and extend. In turn, a qualitative approach is used in cases when the aim is to understand the phenomenon in the certain social context and project opinions and experiences of the subjects under study. (Layder 1993) According to Hirsjärvi and Hurme (Hirsjärvi, Hurme 1991) research does not always strictly follow one approach but can be mixed research which combines these two approaches. However, research often tends to be more one than the other and because of that is said to represent the particular approach. Hirsjärvi & Hurme (1991) and Greswell (2014) state that the qualitative approaches such as interviews and participant observation are suitable when the examinees are studied and when tacit knowledge is believed to exist.

Because this research focuses specially on the case company's current modularisation situation and composing a new modularisation stragy for the case company, a qualitative research approach is selected. This is supported by the fact that in the diagnostic phase the aim is to understand what kind of modularisation initiatives are currently going on and what the case company strives to achieve by modularisation. All this information is held by people who are involved in the company's strategy and development initiatives. As the desired outcome is a new modularisation strategy model and definition of modular construction concept the use of a qualitative approach is justifiable.

From qualitative methods interviews are especially well suitable when the aim is to map out the current situation but also bring out new hypothesis and ideas, that can reveal new connections between phenomena (Hirsjärvi, Hurme 1991). As this is the case in this part of research, interviews as the major data collection method are justified. Furthermore, the interview methods can be roughly divided into three different group: strucured, semi-structured and open interview. A structural interview is the most formal where the questions and the statements form and order is predefined and the same for all subjects of survey. In turn, the open interview is the most informal while semi-structured is something between these two (themes of the interview and structure are predefined but more accurate questions are formed during the conversation). (Hirsjärvi, Hurme 1991). Mapping out the current situation and composing a new modularisation strategy model require discussions with directors and managers, where semi-structured interviews provide a suitable way to structure these interviews without limiting the discussion too much. Through the literature review, the researcher has constructed a good overview about the research subject, which enables an appropriate structuring of the interview themes and questions. In addition, prepares the researcher for emerging aspects during the conversations.

In addition to semi-structured interviews, the Fira Oy's internal documents and participant observation were exploited. Participant observation refers to both systematic and unsystematic unformal data collection (Hirsjärvi, Hurme 1991) which purpose is to expant researcher's knowledge about the subject. Participant observation can happen by participating in the normal day routines in the company such as meetings and informal corridor discussions. In this research the observation was conducted by taking part in steering group meetings and in several workshops. As the participant observation is based on sometimes unsystematic subjective findings it has its limitations. On the other hand, an observation helps to outline the situation and can make it easier to form suitable and accurate interview questions.

5.1.2 Material collection and analysis

Semi-structured interviews were conducted by interviewing people with different background. All interviewees are selected based on discussions and evaluation of who are involved and have the best knowledge. This selection method is supported by Saaranen-Kauppinen & Puustnikka

(Saaranen-Kauppinen, A & Puusnikka, A 2006) by concluding that in semi-structured interviews, the interviewees should be selected from those who are believed to have best knowledge about the phenomenon.

ID	Group	Designation	Company	Duration	ID
	Round 1				
2	Management	Director Residential construction	Fira Oy	1h 10	I2
3	Developement	Construction	Fira Oy	1h 6min	I3
4	Developement/design	Head of Residential Development	Fira Oy	110 min	I4
5	Design mangement	Design Manager	Fira Oy	70 min	I5
6	Design	Architect	Fira Oy	50 min	I6
7	Procurement	Procurement Director	Fira Oy	74 min	I7
8	Residential construction	Project Manager	Fira Oy	64min	I8
9	Cost accounting	Cost Accounting Manager	Fira Oy	65 min	I9
10	Production	Head of Residential Production	Fira Oy	54 min	I10
12	Ship building	Head of modularisation / modularisation specialist	Meyer Turku	54 min	I11
13	Structural design	Project Manager	A-Insinöörit Oy	57 min	I12
14	Architecture design	Strategy Director	Arkkitehtipalvelu	60 min	I13
15	HVAC design	Project Manager	Rejlers Oy	59 min	I14

Figure 15 Interviewees

The interviews were based on six themes:

- Introduction and orientation question
- Modularisation strategy
- Traditional - and modular supply chain
- Modularisation of ship building industry
- Modular design library roadmap
- Free discussion, interview development proposals

The interview structure is presented more precisely in appendix 1. The same interview structure was used and somewhat covered with every group. However, interviews emphasised different themes with different groups according to their knowledge and position. The questions were divided into two levels, so that the first level represents a more general level of the subject matter which was then followed by the more detailed second level questions. If the interviewee was not indicated to possess any more information after the first level, the second level questions were not introduced. Modularisation of the ship building industry theme was naturally discussed just with the interviewees from that industry. All interviewees in Fira's organisation are involved directly with modularisation at some extent, but some groups are less involved with business models. This fact supports focusing more deeply on different research questions with different groups.

The interviews were conducted during May 2020 and September 2020. Due the Covud-19, all interviews were carried out as a remote-meetings by using Microsoft Teams. The interviews were conducted in Finnish which is the language of the interviewer and all interviewees. To make analysis phase easier and to enhance reliability all interviews were recorded. The permission for recording were requested from all interviewees. The first interviewee gave a good indication about the length and structure of predesigned interview. The length was around

60 minutes and the first interviewee didn't see ambiguities in the structure so the modifications after first interview were minimalistic and focused more on trimming the overlapping questions.

5.1.3 Material processing and analysis

To ease the workload, the interview's recordings were transcribed by using a transcription firm. The transcription was conducted by utilising basic level transcription, or in other words, all speech is transcribed but fillers and words unrelated to the theme are left out (Hirsjärvi, Hurme 1991). The material was first transcribed to word document and then transferred to an appropriate excel sheet where all interviewees basic information and interview questions were coded to one table. Moreover, the material was classified first into themes that correspond to interview themes and then into research questions. Again, the answers were also transformed to a shortened clear version that makes analysis easier. The analysis was conducted by focusing on one theme and searching repetitiveness, similarities, exceptions and comparing answers to researcher's own literature-based knowledge about the theme (Saaranen-Kauppinen, A & Puusnikka, A 2006, Hirsjärvi 2015).

After analysis of the material, a synthesis was composed by utilising an abductive reasoning process that combines inductive and deductive reasoning (Hirsjärvi 2015). The inductive reasoning is based on individual perceptions which are then transferred to generalised theory, whereas deductive reasoning progress from generalised theory towards details using known facts (Dubois, Gadde 2002). In abductive reasoning process (figure 16) the researcher already has some theoretical suppositions or ideas based on litarure review. According to Dupois and Gadde (2002), this enables researcher to utilise knowledge from literature and material collected by using empirical methods as a combined developing system. In practise, this meant that researcher was able to utilise the aquired knowledge from literature to prepare interviews and in analysis phase, and on the other hand, the revealed knowedge from interviews were utilised to complement the deficient parts in the literature review.

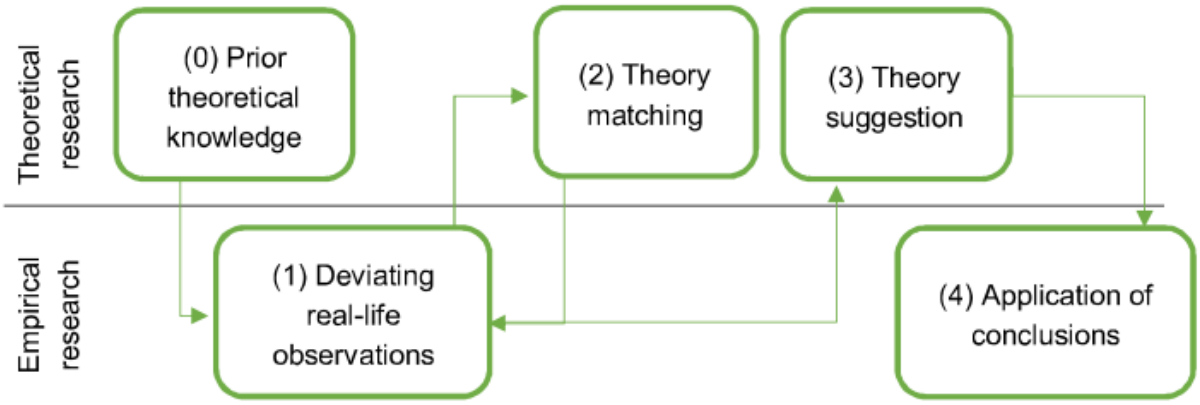


Figure 16 Abductive reasoning process (Kovács & Spens 2005)

5.2 Current state of Fira's processes and readiness for modularisation

5.2.1 Existing design management process and practices

From the design management perspective, a typical design and build construction project can be roughly divided into two parts: designing phase and production phase (figure 17). In addition, the design phase can be divided into the project feasibility planning, predesign phase, building permit phase and detailed designing phase. A project manager with support of a project engineer is responsible for the project feasibility planning, conceptual design phase, schematic design phase and of all building permit activities. On the other hand, a construction project manager with a project engineer support is responsible for carrying out final detailed drawings for production (figure 17). After the design phase project engineer hands over a project to a site manager and a site engineer. (Fira 2020)

Supporting departments such as cost accounting and solution development also take part in design phase by offering BIM-model-based cost estimation during several designing phases. Moreover, HVAC specialist and procurement engineer in cooperation with a project engineer participate in the design management process under a project manager supervision.

In addition, some years ago Fira has reinforced its project management process and introduced a Gate-model where designing phase is divided into eight phases (figure 18). Each Gate contains specific gate-requirements which are then evaluated in a Gate-meetings. The different designing phases are explained in more detail below figure 18. Currently this Gate model is well established way to work in Fira's residential construction unit. (Fira 2020) Because Fira currently is developing the modular designing library and increasing module usage, this current design management process may need to be refreshed.

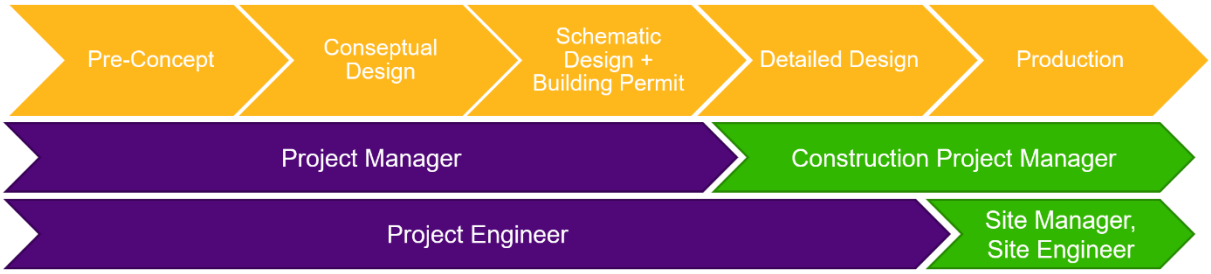


Figure 17 Design management responsiblities in Fira's residential construction unit

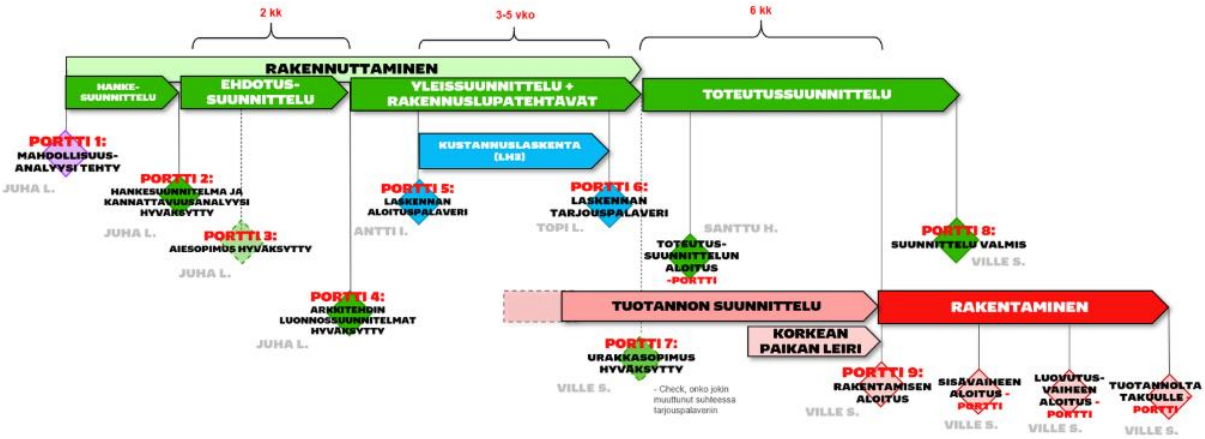


Figure 18 Fira's residential construction gate model (Fira 2020)

- **Pre-Concept phase:** In Fira's process the Pre-Concept (Hankesuunnittelu) phase refers to stage where city plan requirements are reviewed, project feasibility analysis has been made and a project plan is put together.
- **Conceptual Design phase:** During Conceptual Design (Ehdotussuunnittelu) phase an architect draws tentative design concepts which are then estimated by Fira's cost accounting and design management.
- **Schematic Design and Building Permit phase:** Schematic Design (Yleissuunnittelu) phase. In this phase all needed designers are chosen and a detailed schedule for designing is established. During this phase all needed drawings are developed in such extent that the building permit can be applied.
- **Detailed Design:** The detailed designing (Toteutussuunnittelu) phase focuses on producing detailed manufacturing for production purposes.

5.2.2 Procurement department

Fira mainly uses concentrated procurement in its residential construction unit and just small, complementary jobs' procurement responsibility is left to site management. Lately Fira's procurement strategy has focused more on long-term relationships and strives to decrease the amount of single project-focused procurement. Currently, according to interviewees (I3,I4,I7) this means that seasonal contracts are used in the certain strategic materials and Fira has a deeper partner relationship with few subcontractors (I3,I7). However, long term development with suppliers and subcontractors is seen as quite scarce and the idea of utilising construction product industry as a R&D reserve is not well applied (I3,I7). This lack of development with suppliers and subcontractors has many reasons but unique projects and project-focused procurement were seen as the greatest obstacles for long-term development (I3,I4,I7). In addition, one interviewee (I7) pointed out that Fira uses a great number of suppliers and sub-contractors without reliable knowledge about their performance, and therefore selecting the best

partners for long-term partnership has been difficult. The same interviewee also added that this situation is changing due to a forthcoming supplier register.

5.2.3 Readiness to modularisation

The aim of the first theme "*introduction*" was to explore how well the interviewees understand definitions of the terms "*modular design"* and "*modular production"* and how broad the understanding of the current state of modular construction in Finland is. In addition, interviewees were asked how they see Fira's situation in modular construction.

The analysis of the answers reveals that modular design and modular production was extensively understood among the interviewees but some interviewees mixed terms or did not know what they meant. The following question focused on the current state of modular construction in Finland. This question divided the interviewees. Interviewees (I3, I6, I7) indicated that the level of modular construction in Finland is quite good when compared internationally and that in Finland a lot of technology exists and many companies have already done some years modular production. Interviewee's (I4, I5) opinion was more that there has been talks about modular construction, but the maturity level is still very low especially in concrete buildings. Interviewee I2's opinion was that there is modular construction in Finland, but it is not industrialised. The reason why answers were so divided is probably the lack knowledge about building materials other than concrete. However, the common view indicated the modular concrete construction's maturity level is low, and the production is not industrialised.

Fira uses non-volumetric and off-site prefabricated wall elements and slabs in the frame of buildings, which is typical in Finland. Interviewees did not see usage of elements as modular construction, because more or less every project's design process starts from the beginning and often various adjustments for the different element factories are made. Moreover, the interviews revealed that Fira has used bathroom modules and balcony modules (I3,I4,I5,I7) when standardised HVAC-riser modules and HVAC-room modules were new initiatives in Fira's production (I3,I4,I5,I7). The bathroom module "*Modules*" is Fira's own production and the module development has faced some problems related to the module's interfaces and problems related to addressing certain market segments. The balcony modules also are the result of Fira's own module development's, but some problems can be seen that respond to Fira's market segments and end customer demands.

Despite some divided views about the current situation in Finish construction industry and understanding philosophy of modularity, interviewees possessed a common view about Fira's readiness to develop its production system towards industrialised modular construction. Different interviewees highlighted slightly different aspects. According to interviewees Fira's own project development and the forthcoming modular design library are essential components

for developing standardised scalable production. Also, digital management tools and a good relationship with suitable customers were critical factors. (I2, I3, I4) Interviewees I5 and I6 pointed out Fira's organisation's new channels of distributing information and the necessary skills are aspects that have increased knowledge among the organisation. In addition, interviewee I5 emphasised the significance of the recently increased understanding between the site organisation and the head quarter organisation. One interviewee (I2) also wanted to question why certain components or parts of buildings should be modularised and emphasised the production system significance:

> *"Why some component is modular and how, is the question. If production system does not benefit, why some component should be modularised? If we ask this same question every time when we want to modularise something, this drives inevitably to situation that modules and components are in contact with the production system that we use." (I2)*

5.3 Modularisation strategy

The aim of theme modularisation strategy was to review how interviewees experience the current state of modularisation in Fira's residential construction unit. The theme focused on mapping out if there is a clear modularisation strategy, clear objectives and a clear plan of how modularise Fira's residential construction. The important part of interview theme was to reveal if there are different understandings of how modularisation should be performed and how interviewees see the operating environment. The major outputs of this theme were to find vision and clarity for the modularisation objectives and finally how all these are acting together with the production system and the company's strategy. The summary of the modularisation strategy theme is illustrated below in table 2 and discussed in following chapters.

Table 3 Modularisation strategy theme's summary 1

Sub-theme, comments	Interviewees
Is a modularisation strategy clear?	
There is no clear modularisation strategy, some features exist but not clear objectives or study of how to differentiate from competitors or what is our competitive advantage	I3, I4, I5, I6
There is a strategy and it is clear but needs refinition and to be described more clearly	I2
Modularisation exist in Fira's main strategy but don't know if more precice strategy exist	I7
Modularisation objectives and strategy are important to clarify, describe better and perhaps bring new aspects to it	I2,I3, I4, I5, I6, I7
The most important objectives for modularisation are:	
Short lead time (design and construction)	I2,I3,I4,I6
Cost efficiency	I2, I3, I4, I5,
Mass customisation	I6
Sustainability	I2, I3, I5, I6, I7
Rapid cost knowledge	I4, I6
Competitiviness	I3, I4
Scalability perhaps. It might be possible to scale some activity of the production system but the whole modular designing or modular production is difficult to scale	I2
Cost efficiency: Already 10-20% savings has made with standardisation and modularisation and more is to come	I7

Modularisation strategy clarity

The results in table 2 support the researcher's own observations in several meetings that the modularisation strategy is not completely clear in Fira's organisation. Most of the interviewees answered that there is no clear modularisation strategy but some features of it exist (I3,I4,I5,I6). According to two interviewees (I2, I7) there is a strategy but perhaps it is not described well enough and it is not communicated to all employees who are involved. Mostly managers and one director felt that the modularisation strategy is missing, while two directors acknowledged that the strategy exists. Even so, the following question showed that it would be important to clarify and describe the strategy more specifically (I2,I3,I4,I5,I6,I7).

> *" Now some stakeholder group, markets or someone else can resist and tell this is an utopist idea. I would like that objectives should be clarified. Now we do a lot and have some objectives based how we feel. We are thinking and developing here in the small group, but I don't know if we have analysed properly the operating environment. That would clarify those objectives which are possible in terms of market, stakeholder groups, and construction material industry" I4*

Objectives of modularisation

The next subtheme was used to find out what kind of objectives the modularisation strategy should possess. The general opinion among interviewees (I2,I3,I4,I7) was that the objectives should derive from the Fira's main strategy and be parallel with it. The answers were otherwise somewhat divided, and several aspects were pointed out; three following objectives dominated in discussions:

- Shorter lead time (I2,I3,I4,I6)
- Cost efficiency (I2,I3,I4,5)
- Sustainability (I2,I3,I5,I6,I7)

Although, those three objectives meant slightly different things to interviewees. For instance, a shorter lead time in the construction phase was important for all interviewees, while the shorter designing phase was highlighted by interviewee I6. The shorter lead time objective in construction phase should be placed high enough but it should also be realistic. Interviewee I2 estimated that an ambitious but realistic objective could be a 50 % shorter construction lead time than Fira's average in 2020. Although, the same interviewee underlined that many things in several areas need to be done first to reach this objective and it does not just mean modularity. The MDL, modules, standardised components, deep partnerships with suppliers and digital management tools are all needed to have an efficient production system that enables shortening the lead time (I2,I3,I7). In addition, the interviewees I2 and I4 pointed out that in concrete buildings this 50% shorter lead time perhaps also requires an accelerated concrete dehydration process and that should be reviewed more deeply with the concrete industry. The interviewee I2's strong opinion was that the production system defines what type of modularity is needed.

> *"If the objective is to split the lead time in construction phase, it requires certain type of modularity to make it possible. And lots of other things. Then we become to the production system, which one sub-area is modularity." I2*

Even though all interviewees did not emphasise the shorter lead time in the designing phase, they all understood the significance of the modular design library and its standardised solutions, which have a great potential to make the design phase faster. More important was that the produced drawings are efficient to build, drawings are flawless and design solutions are known and without unique variation (I2,I3,I4,I7).

The cost efficiency objective was seen as one of the most important drivers for modularity and therefore as a natural objective. The cost efficiency is a result of many things, and it was somewhat difficult for interviewees to unpack what this objective could mean. However, the interviewee I7 highlighted the savings in the procurement by stating that modular design library and its standardised design solutions have shown 10-20 % cost savings in certain building materials and more similar savings are to come. In addition, shorter lead time in the design phase and in the construction phase, is most likely to affect cost efficiency.

Sustainability was the third objective that popped up as an important aspect in the modularisation strategy. The opinion of all interviewee's revealed that the environment is an important subject and modularity could increase sustainability in residential construction. According to the interviewee I2 sustainability and safety must be at the top level and there is no need for further conversation. The interviewees (I5,I6,I7) opened up the subject more. Interviewee I3's opinion was that sustainability in the construction industry, especially in Scandinavia, will play an even more significant role than it does today. Interviewee I5 stated that if we want to target more sustainability, we need to have objectives and then we need to think about technical solutions such as CO2 tracking and changes in HVAC solutions. Despite this the interviewee I6 didn't see CO2 tracking and environment certificates such as LEED (Leadership in Energy and Environmental Design) as very useful; he also agreed with I5's opinion and emphasised building technical concepts in the sustainability discussion. Furthermore, interviewee I6 didn't see Environmental Social and Government investments (ESG-investments) as a solution for sustainability. Interviewee 6 emphasised modular building flexibility as one sustainability factor. Interviewee I7 possessed a different view about Co2-tracking and environment certificates:

> *"If we use a lot modular construction and we build by doing right at the first time, we most likely do less waste. In the future we can think more about the building life cycle and what is the cost of life cycle for us and for the environment" I7*

> *" our competitors sell buildings with Joutsenmerkki and with other environment certificates and for sure would also support our strategy if we could track and prove Co2 footprint" I7*

In addition, a rapid negotiation readiness with customers utilising MDL arose in the interviews, but that was seen more as a subobjective or as a competition advantage (I4). Scalability was seen as an important objective as well, but there we need to make a distinction between Fira's normal construction business scalability and with new scalable business models. Modular design library and Fira's production system's aim is to create a scalable construction concept which uses standardised components and modules. New scalable business models were seen more as an important possibility to create new side stream business as the interviewee I2 stated it.

> *" It is perhaps possible to scale some part of our production system or side streams but I doupt that we can transfer the whole modular designing library or modular construction to new scalable business." I2*

The following subthemes focused on mapping out how interviewees saw Fira's operating environment and competitors in modular construction. Table 4 below illustrates how competitors were seen in three different segments. The first segment refers to competitors who already have modular production in wooden apartment buildings. The second segment presents

competitors who have modular construction initiatives in concrete construction. The third segment is bathroom module manufacturers. Interviewee I2 underlined significance of studying competitor's production systems, instead of just their building's modular architecture.

Table 4 also shows that the interviewees identified several competitive advantages which could differentiate Fira from other competitors. For instance, MDL with Fira's own project development was recognised as a combination that other competitors don't have in the same sense (I3,I6). Moreover, innovative financing products and affordable housing concepts supported by MDL arose in many conversations. Modular design library also enables rapid study of market leads and free plots which was seen as a great advantage. Also, a prompt readiness to bargain with customers was seen as a significant competitive advantage. Interviewee I2 highlighted long-term cooperation with partner networks and existing construction product industry, which allow shared development costs and enables learning.

Table 4 The modularisation strategy theme's summary 2

Sub-theme, comments	Interviewees
The most important competitors in modular wood construction:	
Lehto, Skanska boklok	I3, I4,, I6, I7
Adapteo, Lapti	I3, I6
The most important competitors in modular concrete construction:	
Lehto	I2,I3, I4, I6, I7
YIT	I3, I4
Competitors production system needs to be taken into account when we analyse who are our competitors	I2
The most important competitors in bathroom modules:	
Parmarine	I6
Bonava	I6
How Fira could differ from competitors?	
Fira's own residential project deloping and understanding of production technology	I3
Rapid negotation readiness	I4
Modular design library	I6, I3
Affordable hausing and innovative financing innovations	I3, I7
partner network and broad utilising of existing industry	I2
Innovative environment and narrower gap between office and building site	I5

After mapping out competitors and competitive advantages the interview continued to study customers and other stakeholders. Comments are presented in table 5 which address the

questions, “who are the most important customers for modular construction?” and “what major stakeholders could benefit out of modular designing and construction?”

Table 5 The modularisation strategy theme’s summary 3

Sub-theme, comments	Interviewees
The most important customers for modular residenttial production:	
End customers who seek affordable housing	I2, I3,I4,I6,I7
Rental house investors and Institutional investors	I2,I3,I4,I6,I7
Joint building ventures	I6
Perhaps smaller constractors who don't have a production system could buy this as a franschising service	I2
I recognise also our suppliers who are involved to this sysmen as our customers.	I2
Benefits for the major stakeholders:	
Main contractor	
Standardised design solutions enable standardised production systems which can be developed more easily since learning happens faster with standardised design solutions. Lead time should be shorter, quality should be better and quality management can be more efficient, safety at building sites can be at better level.	I2,I3, I4
More profitable scalable business with faster capital recycling even with smaller project margins	I7
Suppliers, sub-contractors, designers	
Longer view to future, longer production series,	I3,I7
A platform to develop products and invest to R&D	I3,I7
Customers (Institutional investors)	
Short lead time and fast capital recycling	I2,I3,I4
Authorities	
Easier decicions when fitting building mass into the plot, because with designing library the changes can be demonstraded instantly during the meetings	I3,I5,I6
With standardised appartment and solutions permit authorities could do their process more efficiently	I3,I4,I5,I6
Inhabitants and society	
Affordable apartments with high quality. Sustainable hausing due less loss during the building process	I2,I3,I5, I7
Inhabitants demands are taken better into account by utilising mass customisation	I3,I6

Most important customers

As we can see from table 4 the interviewees hold the common view who are the most important customers for modular construction. According to the interviewees (I3,I4,I6,I7) the most important segment is rental apartment markets and their institutional customers. In addition, end customers or in other words inhabitants who seek affordable rental or owner-occupied flats were also seen as a major customer group. This group was seen as important for Fira's cooperative housing concepts which could be one channel for Fira's modular residential production. One interviewee I6 also mentioned Joint Building Ventures as one major customer group. In turn, other interviewees were more skeptical about developing projects to individual customers as a core business. However, in the future the situation may change if Fira can establish an efficient modular mass customisation. (I3) The interviewee I2 saw suppliers and perhaps other smaller contractors as possible customers. Moreover, the interviewee I2 again underlined the significance of production system and modularity as a part of it.

> *" this cooperation housing model makes sense for me because I believe that younger people than me doesn't value so much ownership off own flat, and possessing a huge mortgage is not only way to live and measure own success. Instead, these different types of living, rental and others, if we have solutions to this there is a quite big customer group" I7*

> *"Perhaps some smaller contractors could buy Fira's production system as a franchising who don't have own production system. This could be like an elevator to higher level operation which again brings significant competitive advantage for those firms" I2*

Benefits for stakeholders

From table 5 we see that interviewees found possible benefits for each five major stakeholder groups. Interviewees felt that sharing benefits is essential to get other stakeholders interested in participating in the development of the modular design library and Fira's production system. According to interviewees (I2,I3,I4) the most significant benefits for the main contractor are standardised design solutions and a standardised industrialised production system which enable fast learning. This should lead to a shorter lead time, better quality and to better safety at the building site. According to the interviewee I9 a shorter lead time could bring significant savings in the project's general conditions expenses. A basic project with 100 apartments possesses around €100 000 of monthly general condition expenses, and there is a possibility to make great savings with better production flow. Interviewee I7 emphasised scalable business with faster capital recycling. According to Interviewee I7 the projects margins could be even lower if the projects lead time is short enough and the capital recycling is faster than it is now. For suppliers, sub-contractors and designers participating in modular design, library would offer a longer view to the future and a more stable business. In addition, for suppliers the modular design library could encourage them make R&D investments and develop their own business more productively. (I3,I7) Customers would benefit from shorter project lead time and faster capital recycling meaning better business for them. According to the interviewees (I3,I4,I5,I6)

authorities could benefit from standardised solutions and over time perhaps make their building permit process more efficient with Fira. Finally, the inhabitants and society would benefit due to the affordable, sustainable and high-quality housing (I2,I3,I5,I7).

> *"The price level is completely different when suppliers and sub-contractors see in the future. they can invest more and then the operating is more efficient. Smaller sub-contractors could grow with us because we can ensure longer view in future instead that we can't tell when we do next tie with you" I7*

> *" This opens the gate for partnership thinking and industrialised production" I7*

5.4 Traditional supply chain towards modular supply chain

This theme is divided into seven sub-themes. First subtheme maps out how interviewees see the problems in the construction supply chains in general. The following sub-themes aim to review how the situation is in Fira's own supply chains and how MDL could change it.

Table 6 Traditional supply chain towards modular supply chain

Sub-theme, comments	Interviewees
Major problems in residential construction supply chain	
Unique projects and project-based procurement	I3,I4,I7
We can't offer a longer view for our suppliers and take their opinions into account in development and designing process	I7
Fira's supply chain now	
Longer seasonal contracts has existed, but not much long-term development with suppliers	I3
Suppliers capacities has been partly unknown due the lack of a sufficient supplier register. The register is now almost ready and will offer proper tools to regognise the key partners	I7
Cooperation with bathroom modul company has been difficult partly because of different objectives and incentives	I3
How to change supply chain with modular design	
Utilising standardised solutions with a great volume enables to harness designers, suppliers and contractors into deeper partner relationship and long-term development	I3,I4,I7
Project-based procurement decreases and tendering processes are not needed always	I4,I7
Review of subcontracting scopes should be studied more deeply	I4,I7
Modular designing library and standardised components enable suppliers' performance tracking. With the supplier performance tracking we can collect neccesary information to develop components and modules.	I7

Characteristics of traditional supply chain

Table 6 summarises the interviewees' answers related to supply chain theme. All interviewees stated that in general the major problems in construction companies' supply chains are unique projects and project-based procurement (I3,I4,I7). Moreover, suppliers and sub-contractors often change and are often taken too late into projects and their opinions and development capacity are poorly utilised. In general, a project-based thinking was seen as the major obstacle to develop supply chains.

According to interviews Fira has strategic long-term contracts with suppliers but long-term development with suppliers has been quite small. One great problem has been the lack of a proper supplier register where supplier's and sub-contractor's capabilities and capacities are tracked. However, this is changing due to the forthcoming register. (I7) Interviewee I7

underlined the importance of the register in the partner selecting process. With the register it is easier to define how deep cooperation and long-term development with a certain supplier should be.

How modular design library could change supply chain

All interviewees highlighted the significance of MDL's standardised solutions in the sense of building deeper partnerships with suppliers, contractors and designers. In addition, MDL would enable better utilisation of suppliers' R&D capacities. (I3,I4,I7) Interviewees I4 and I7 also saw that project-based procurement decreases when buildings are designed using library's solutions. Interviewee I7 explained how modular design library, standardised components and modules enable suppliers' performance tracking. According to the interviewee I7 data-based development is an essential asset and it provides the opportunity to tell suppliers exactly where they are doing well and where they need to develop.

> *"what are the Fira's residential construction major missions, for example if there is some things what we want optimise such as lead time in general or installing time per component and price per installed component, these are the things what we need to track in supply chain and think how our partners can participate to these objectives" I7*

Table 7 Summary 2 of traditional supply chain towards modular supply chain

Sub-theme, comments	Interviewees
Ownership in module developing	
Cooperation model in module development is probably the best way. On the other hand, a case where an ownership in some key module brings more value for Fira, the investment to own module production could be considered	I3
Coopreation and networking is better way to develop modules and components	I4,I2,I7
Fira owns a bath room module factory and if we see some other module is valuable develop and manufacture ourself it possible	I2
Global supply chains	
Global supply chains probably don't posses a great potential for Fira's residential construction. Perhaps in wooden modular construction.	I4,I7
Organisation changes	
Modularisation and modular design libarary need more competences and more man power, but I am not sure is it a new position or subordinated task to someone.	I3,I7
Probably there will be new tasks related to modular design library. I am afraid that it would be administrative position and people are not excited. Rather some project manager or procurement engineer tasks would be extented to cover also modularisation.	I4
New competences and man power is definetely needed. Should be completely new position. Otherwise projects will always override and time to think development things is limited.	I5
New competences	
We need more people with capasity to develop, integrate and posses good network management skills and cooperation skills	I3, I4, I7
We don't need people with short term thinking who are focused quick victories at expense of our partners and other suppliers. .	I7
We need more people who understand this modularisation with technical skills	I5

Ownership in module development

Table 7 continues summarising rest of the questions related to the supply chain theme. The interviewees shared the common view that partner network is the main channel to develop and manufacturing modules (I2,I3,I4,I7). On the other hand, Interviewees I2 and I3 both stated that this should be reviewed “case by case”, and if some modules are strategically important and bring value for Fira it is possible to develop and manufacture them in-house. However, both interviewees highlighted that it is not necessary to develop modules in-house or own module manufacturers but interviewee I3 added that often ownership gives more influence and therefore makes steering of companies easier.

> *"somehow, I see that this should be reviewed through the owner-value, and how much it is profitable to invest money and competence. Also, with some cooperation models we can invest our own competence and product development. If we see that some module has a greater potential and Fira could bring more value with its own capital or with organisation allocation, and if it produces more value to owners then it could be worthwhile"*

The next question about global supply chains did not divide interviewees. Both interviewees I4's and I7's opinion was that modularisation does not significantly increase the global supply chain potential in Fira's residential production especially in concrete buildings. One exception could be the modular wood production where module factories exist in Baltic countries and in Poland (I4,I7)

Organisation changes

The question about organisation changes divided interviewees in some respect. When all interviewees agreed that modular design library and modular construction will reveal new tasks, interviewees were careful in their opinions on how these tasks should be done. For instance, interviewee I3 opinion was that when module or library development has more volume, someone needs to have ownership of it. Although, the interviewee I3 and I7 did not know who this person should be and whether this should be a completely new position or just side tasks for someone; it depends on the volume. Interviewee I4 also recognised new tasks related to modular design library but was afraid that if it is a new position it will become too administrative, and people are not excited about that. According to the interviewee I4 a better option is to spread new tasks to project managers and procurement engineers who need this design library in their work. In addition, the development initiative pulse should come from project development and from production and therefore, for instance, a modularisation manager or similar is perhaps not the best option (I4). Another opinion was presented by the interviewee I5, who underlined the need for a completely new position related to modularisation. Interviewee I5 was afraid that if new tasks were allocated to project managers and procurement engineers, the projects would override modularisation development and it would be difficult to find enough time to focus and think.

New competences

Almost all interviewees agreed that modularisation and modular design library need people with good product development, network management and integrating skills (I3,I4,I7). According to the interviewee I7 the traditional project-based haggling should shift more towards cooperation and that requires different skills such as interaction and management of different networks without superior position. Also, skills related to the involvement and influencing of stakeholder groups become important. In addition, long-term thinking in the building site organisations is important too and should not be ignored. (I7) The interviewee I5 also emphasised technical competence with software and good product development skills.

> ”it *should be very active person who can work hands-on, would listen all the time feedback from the production, customers and from designers and actively dig new information*” I4

5.5 Ship building industry applications

One objective of this research was to review how modularisation is performed in the Finnish ship building industry and what kind of changes modularisation has caused to the shipyard’s supply chain and operation environment. Two of Meyer Turku shipyard’s modularisation team members were interviewed, and answers are summarised in three different themes (table 8): modular philosophy, changes in supply chain and modular design library.

Table 8 Summary of modularisation in ship building industry

Sub-theme, comments	Interviewees
Modular philosophy	
Modularity as a filosophy should be understood before you can think about other things. System approach is the key word. Production system, schedule management, customers, organisation aspect, suppliers etc has to be considered§. We can't always force our production system how we want it, instead we must also study what brings value for other stakeholders	$I11_2$
Meyer Turku has founded a development unit which major mission is to enhance modularisation thinking in shipyeard's own organisation and suppliers organisation.	$I11_1$
Partner selection plays a key role in long term module and component development and gained benefits should be spread fairly	$I11_1$
Because an opportunistic behavior can ruin easily a good partnership, this should be taken into account when hiring people.	$I11_1$
Changes in supply chain	
Cabin modules have been used over 30 years but lately specially technical system modules has turned out to be efficient and have increased productivity.	$I11_1$
Modularisation has not increased the usage of global supply chains.	$I11_1$
Suppliers who understand signifigance of modularisation and long term development have increased their R&D investments	$I11_1$
Power balance in the market has not shifted much due the designing library. Allthought, in technical solutions the shipyard have more power to decide.	$I11_1$
Modular design library	
Modular design library is used in predesign phase and designers use standardised modules and components. In this maturity phase assemply drawings are drawn by designers.	$I11_2$
Desing library is builded into design softwares. In the future a register management and design conficurator are coming to complement usage of the library.	$I11_2$
Designing process is divided to predesigning phase which is conducted by in hause designers and assembly drawings phase which is outsourced to design consults.	$I11_1$
Designing filosophy and library must be communicated also to customers and other stakeholders and take also their opinions into account. Otherwise we may end up to situation where we have a great pile of modules and component that no one want.	$I11_1$
Because the shipyeard owns all drawings there is not much copyright problems.	$I11_1$

Modular philosophy

Both interviewees $I11_1$ and $I11_2$ underlined the significance of understanding the philosophy behind modular design and modular production in the their own organisation, but also in other stakeholder groups. Therefore, according to interviewee $I11_1$ Meyer Turku has founded a modularity development team with five specialist whose major tasks are to shape thinking, educate and create partner networks who understand the philosophy of modularity and its connection to better productivity. According to interviewee $I11_2$ the system thinking is the better way to approach modularity than, for instance, from the architecture or from the production system's point of view. In modularisation, many different aspects should be considered such as product architecture, production system, customer demands, organisation aspect, supplier network and so on. Interviewee $I11_2$ also pointed out, that if they push too much of their own opinion of the production system, the suppliers and other stakeholders may become offended. Instead, what is valuable to the stakeholders should be studied first ($I11_2$). The interviewee $I11_1$ underlined the importance of selecting the right partners who have will, understanding, enough competence and resources to start the long-term development of modular components. In addition, it is important focusing on one's own organisation, and to identify what kind skills and features are important in long term development.

Changes in supply chain

According to interviewee $I11_1$ there has been some wave of movement in usage of modules in the Finnish ship building industry. Lately, the increased understanding in modularity and design technologies have made machinery modules very efficient and increased productivity there. The machinery modules especially have decreased the lead time ($I11_1$). Those suppliers and sub-contractors who have understood the significance of modularisation have increased their R&D investments and got promising results in productivity. According to the interviewee $I11_1$ modularisation has not increased usage of global supply chains and currently shipyard strives to use domestic partners. Interviewee $I11_1$ opinion was that the power balance in product decision making in the markets has not changed much due to utilising the design library. However, in technical solutions shipyard now has more power to decide and shipyard strives to change the situation in other areas as well by increasing the knowledge about the benefits of modularity for architects and customers and other stakeholders.

> *"Best companies who have sophisticated workshops have calculated that they save 70% of time if they invest 20% more to designing modular component structure"* $I11_1$

Modular design library

According to interviewee $I11_2$ the shipyard has created a modular design library which consists of standardised components, modules and design rules and instructions. The efficient use of design library means that it should be built into design sofware. In the future, register management and design configurator tools will be added to make the designing process more efficient and complete. Interviewee $I11_2$ also explained how the designing process is performed.

Shipyard currently uses in-house designers in the predesign phase which uses design library, and then detailed design is outsourced to external consults who compose drawings for the production. Although, the library develops and the process changes during each maturity step. ($I11_{2)}$ The interviewee $I11_1$ pointed out the significance to communicate the design library to customers and other stakeholders and take their needs into account in the development.

> *"otherwise we may end up to a situation where we have a great pile of modules and components that no one wants"* $I11_1$

5.6 Modular design library

Table 9 summarises different stakeholder opinions about aspects that should be taken into consideration in the building process of MDL. Almost every person in Fira's organisation and other stakeholder organisations had different sorts of aspects that should be considered. However, three major groups can be recognised throughout Fira's managers and external design consultants: software technical functionality, copyright matters and designers responsibilities (I3,I4,I5,I7,I8,I13,I14,I15). Open questions in software technical functionality were mostly related how the designing happens in practice by using predesigned apartment blocks, and on the other hand, how different software are compatible with library usage. Also, designers were especially worried about their own software tools copyrights because they have significantly invested in them and it is part of their competitive advantage. In turn, Fira's organisation was worried about copyrights of MDL and where it should be stored and maintained. Also, the designer's responsibilities in situations where they use someone else's predesigned components and apartment blocks, sparked debate along several interviewees. Other repetitive aspects in interviews were procurement and suppliers linking into library development and library's maintenance.

Table 9 Summary of aspects that should be considered in modular design library development

Sub-theme, comments	Interviewees
Interviewees' I2-I6 opinions	
Production system is the king. Also paying attention on the existing construction product industry is important	I2
Copyright procedures are important to think throught	I3,I5
Residential construction strategy and business plan is important to keep in mind when we develop the modular design library	I4
Solve how designing happen in practise by testing	I4
We have to make sure that we have enough resources and competences to develop. Currently IT department is needed to solve software problems	I5
We should plan in more detail our partnerships with designers	I5
Different department's and other stakeholders' opinions	

Procurement I7
1. Scheduling between modular concept and procurement
2. Need for new type of know-how and skills
3. Sofware's techinal functionality
4. Pilot projects' feedback

Project Managers I8
1. Authorities and detailed city plans
2. Inhabitants' desire to influence to the apartment
3. Desing consultats' responsible questions
4. Design contracts' content in future

Cost accounting I9
1. Systematic mistakes in drawings
2. Production needs should be the source of development
3. Challenge of suppliers little by little
4. Modular design library's maintenance
5. Authorities' intepretations

Architect I14
1. Number of pre-designed apartments
2. Softwares cross-functionality
3. Copyright matters
4. Library's Maintenance and flexibility

Structural designer I13
1. Modula model vs structual functionality
2. Software's cross-functionality
3. Documentation management. Where predesigned files are?
4. Software versions
5. Designers own design tools copyrights
6. Element sizes and electrification

HVAC designer I15
1. New software versions
2. Library's maintenance
3. Responsibility questions

5.7 Peformance tracking

Table 10 illustrates the interviewees' opinions about how MDL performance should be tracked. Interviewees I2 and I3 believed that lead time, quality and project costs should be measured. Again, lead time should be measured during the design phase and the construction phase. How quality should be measured was not perfectly clear into interviewees but one idea was to measure the data during construction phase, and the second idea was to measure post-handover phase's repair costs. According to interviewees I2 and I3 the project's costs in general are the third important indicator. While the interiewee I2 suggested that a good measurement unit could be per apartment, the interviwee I3 recommend per square meter. The majority of interviewees agreed that design lead time and costs alone are a bad indicators and quality tracing should be followed at the same time. Interviewees I6 and I7 also brought out one indicator related to level of component standardisation and expressed that some objective there would be helpful.

Table 10 summary of performance tracking

Sub-theme, comments	Interviewees
Lead time, quality, euros. Perhaps per apartment is a good indicator.	I2
Lead time, quality, euros. Perhaps per appartment square. Also track regord about investments to modularisation.	I3
Desing costs, feedback about drawings, designing lead time, production costs, construction lead time compared to 2020 builded buildings.	I4
Design costs is not good indicator alone. If designing is cheap and fast but drawings quality bad, the design lead time doesn't matter. Feedback from production and repair costs need to be considered aswell.	I2,I3,I4
Design costs , feedback about drawings, procurement standardisation level. It is important to implement tracking when library is more complete.	I6
Standardised components share of all components. Some objective should be placed in some point. We have to know what we want to standardise and what is the current level	I6,I7

6 SUGGESTION FORMULATION AND DEVELOPMENT SUGGESTIONS

In this subchapter the collected interview material is evaluated with the findings of the literature review. Moreover, the development suggestions are formed and again the strategy model and the maturity model are created and presented in subchapter 5.10 and 5.11.

6.1 Development suggestions

6.1.1 Modularisation strategy

The modularisation strategy was not clear for most of the interviewees and many of them felt that the operating environment analyses and objectives would bring more clarity to MDL's building process. Also, ambiguity to understand modularity from different aspects occurred in the interviews. According to Peltokorpi et al (2018) the modularisation strategy's job is to clarify the objectives of the modular production system, and moreover define how modularity should be exploited in different domains of modularity. In addition, Campagnolo and Camuffo (2010) explain how modularity objectives affect to modularity definition and the way how to modularise. Few interviewees regocnised this connection between objectives and modularisation. In further discussion same interviewees revealed few in-house module development-cases where modularisation objectives were not synchronised with Firas strategy or with market fundamentals. Therefore, clarification between modularisation objectives and Fira's strategy were underlined in several interviews.

The analysis of the interviewees answers shows that the objectives were not clear for most of interviewees. However, few interviewees underlined that the objectives should be aligned with Fira's residential construction strategy. Interviews answers presented a broad set of objectives for modularisation but three major objectives rose up from various opinions. Short lead time, cost efficiency and sustainability were seen as the most important objectives for modular construction. Also, scalability was aspect that rose up in the interviews. Peltokorpi et al (2018) also regocnise in their strategy model a lead time and a cost efficiency as major objectives for modularisation. Although, their model does not identify sustainability as an objective, though flexibility in use could be seen sustainability. However, Peltokorpi et al (2018) model is generalised and not created for one certain company and so it should be modified to right context.

Understanding the growing need for affordable housing and Fira's residential production strategy were clear for all interviewees and therefore the most important customer segments for MDL-projects were well recognised. According to authors such Erikstad (2009), Erikstad (2019), Brathaug et al (2008), Campagnolo and Camuffo (2010) and Gosling et al (2016) modularisation and modular design libraries can offer several benefits for different stakeholders at certain phase of project or production. Also, interviewees regocnised many of these benefits for different stakeholders at different stages of projects.

Development suggestions

The modularisation strategy and the objectives should be discussed properly among the organisation and especially in teams who are responsible of developing MDL. Moreover, as Campagnolo & Camuffo (2010) state a product, process and organisational aspect should be considered equally in long-term modularisation strategy. Also, aligned with Baldwin et al (2000), market studies and stakeholder's opinions should be analysed well during MDL building process and before component standardisation or modularising some part of a building. As Voordijk et al. (2006), Bertelsen and Koskela (2005) and Baldwin and Clark (2000) underline, the interfaces should be well designed and standardised between modules and components, and they should mirror the work tasks and organisation boundaries. Finally, the most important is to approach modularity and modularisation from system perspective and to avoid one aspect dominance.

6.1.2 Ship building industry applications

The interview with the ship building industry underlined the significance of understanding the philosophy behind modular design and modular production. As Campagnolo & Camuffo (2010) enhanced the equal respect for product, process and organisational elements and Balwind and Clark (2000) underlined the significance of stakeholder's interests at the certain production phases, also interviewees felt that system thinking is the right approach in modularisation. Therefore, product architecture, production system and organisaiton aspects needs to be considered simultaneously. In addition, stakeholder's interests should be studied and considered in ship components standardisation and module development decisions. To spread understanding further in the ship building industry and develop new modular solutions with partners the shipyard has founded a five-member modularisation team.

The investments in capabilities, increased understanding in modularity and improved design software have enabled to create new efficient modules and made possible to start developing a modular design library (MDL). Also, Erikstad (2009) and in his further studies related to Ultstein shipyard support that investments in designing platform and module development can increase speed and quality in the design and tendering phases, and in turn, cost savings with longer manufacturing series and again shorter lead time in production. According to the interviewees, even the industry modularisation maturity level is not yet high, still some good results in productivity has been proven and suppliers who understand the modularity has shown activity in R&D investments. In turn, the interview revealed that modularisation and the MDL have not been increasing use of global supply chains which was happened in Ulstein case in Norway. Some explanations could be the different strategy, labor availability or different maturity level of modularisation. Erikstad's (2009) suggested impact to market power balances were not seen yet on a large scale in the Finnish ship building industry.

According to the interviewees MDL should be built into design software. This is important for efficient use of the library as a design platform and again allow further complementary tools integration in the designing software. When the MDL maturity level is at the required level, the complementary tools such as library management and configuration tools can be added to provide more efficient and broader use of MDL. The similar design platform approach is illustrated in Erikstad (2019) study of Ultstein shipyard; in addition, Meyer Turku's vision follows mainly Erikstad's definition of design platform: "*a structured, coherent collection of resources, including systems and template hierarchies, textual components, variants, rules and interface definitions, from which a range of customized product definitions can be derived*" (Erikstad 2019). Even the MDL is not ready, Meyer Turku's case shows that they have a quite clear vision how MDL should be created and what kind of software technology it requires.

Development suggestions

Fira's MDL project and the modular construction concept require balanced focus on product, process and organisational elements. Moreover, stakeholder's interests are important to be considered in modularisation. In practice, this could mean mirroring the MDL also to the Fira's residential development processes and possibly to new tasks or positions in Fira's own organisation. Resources could be wise to allocate to also educate suppliers organisation and in general shaping thinking in the industry. Moreover, long-term development teams with suppliers could be one way to increase knowledge in partner organisations. Fira should also seriously consider developing MDL which is built into design software and is capable utilising 2d and 3d designings. Also, later when maturity level allows, complementary tools related to component configuration should be considered.

6.1.3 Traditional supply chain towards project-independent supply chain

Major problems in residential construction supply chains were well regocnised among the interviewees. Aligned with Vrihoef and Koskela (2005) and Ballard and Howell (1998) the interviewees stated too that unique projects and project-based thinking in general are the major problems that obstruct productivity improvements in the industry. Again, Fira is also dealing with the same problems in their supply chains but due the many improvements in procurement and MDL project the situation has a great chance to improve. For instance, the supplier register enables the selection of the most capable partners for long-term development projects. Secondly, interviewees underlined the importance of the MDL in standardisation of components. This can offer a longer view to future for suppliers who's components or modules are standardised into the MDL, and so enables longer manufacturing series. Same findings were also illustraded in Erikstad (2009) Ulstein shipyard case study and in Meyer Turku's interview. According Fira's interviewees MDL also makes possible supplier's performance tracking which is widely used in other industries to develop suppliers. With supplier's performance tracking Fira can integrate its own objectives to supply chain and facilitate the development and possibly even steer suppliers R&D investments to right areas. In general, the interviewees

supported module development in cooperation with existing industry. In turn, few interviewees analysed the possible scenarios when module development could be reasonable to do as an in-house project. Also, according to Campagnolo and Camuffo (2010) and Sako (2003) there is no simple answer which path is to right in module developing, and it is highly depended such attributes as firm strategy, industry maturity and firm capabilities. Erikstad (2019) argued that modularisation in Norway's ship building industry has enabled the use of global supply chains. However, like in Turku Meyer's case in Finnish ship building industry, the global supply chains were not seen possessing a great potential for Fira's residential construction. Although, few interviewees mentioned that perhaps in the wooden modular buildings global supply chains could play a more important role than in concrete buildings.

Interviews supported partly the literature findings how organisation should mirror modularity. the interviewees agreed that new tasks will appear in the module and in component development, as well as in the MDL development, usage and maintenance. Interviewees were not sure how these new tasks should be performed. Few interviewees supported idea where new tasks would be allocated to existing positions. Those interviewees who worked more hands-on in projects opinion was that, if the new development tasks are allocated to project managers or procurement engineers, the normal projects always override the development. Network management skills and cooperation skills were seen important qualities in deepening cooperation with suppliers and other partners.

Development suggestions

Procurement and MDL development team should consider together how to implement the suppliers's performance tracking in the most important modules and components. Moreover, the new supplier register's data could be exploited in the identification of supplier candidates when developing MDL solutions. Likewise, Campagnolo and Camuffo (2010) argued about interfaces, the subcontracting scopes should be reviewed critically and strive to identify boundaries and interfaces which mirror better the components and modular architecture in MDL. Module development decisions should be reviewed case by case and consider attributes as firm strategy and value, existing industry maturity and firm capabilities. Fira's own bathroom module factory could be a possible asset to use in some development projects, perhaps also in cooperation with some other supplier. New tasks due modularisation should be first identified and evaluated, and again then allocated or set up to new position(s).

6.1.4 Modular design library

Erikstad (2019) defines design platform with one sentence as: ""*a structured, coherent collection of resources, including systems and template hierarchies, textual components, variants, rules and interface definitions, from which a range of customized product definitions can be derived*". The Erikstads definition of design platform also applies quite well to Fira's MDL project content and many of the interviewees had similar thoughts of MDL definition,

granted that there were different opinions what should be the final result. Also, the possible benefits of MDL were quite well identified among Fira's organisation and external designers. The big questions are; how to build it? and what kind of stakeholder's interests should to be taken into account? Interviews of different stakeholders revealed that there is a great number of different interests that are important to consider in MDL building process. Currently, the major problems are related to diverse design software usage among designers. More specially, how to solve different design software cross-functionality and synchronised library maintenance. There is danger that, if something changes in the MDL and there are various software and various consultants maintaining them, how the MDL stays syncronised. The second aspect which is not clear to interviewees is the current development level of MDL and which direction the development should proceed. Without the clear picture of the maturity level it is also difficult to communicate MDL development to other stakeholders. For instance, designing interfaces to production system and other further improvements such as configuration tools is challenging. Moreover, smaller problems are easier to solve when the artifact is defined. Participating to several meetings related to MDL development revealed that even there is roadmap for MDL project the documenting of development progress is missing.

Development suggestions

The major problem is related to software environment. Therefore, the design software problem needs structured approach and well documented questions and objectives before IT-specialists can participate to problem solving. Secondly, well designed maturity steps for MDL could bring clarity to development process and facilitate communication about MDL in Fira's organisation and to other stakeholders. A better defining of MDL could also help to increase interest among Fira's partners towards MDL.

6.1.5 Performance tracking

As Erikstad (2019) argued, it makes sense to continue spending resources in platform development as long the net productivity and quality in exploitation phase is positive. Therefore, even the MDL itself is just one aspect that affects on project's performance, it may enable many further improvements and therefore the data from MDL projects is valuable. According to the interviewees the MDL development and performance should be measured. Especially a lead time in the production phase was seen an important indicator. Also, a lead time in the design phase was proposed as one measurement., which however, was seen more problematic indicator. Erikstad (2009) brought up a fast tendering process during predesign phase as a significant competitive advantage in ship building industry. This is also the case in residential construction according to interviewees. Therefore, perhaps a better measure is tendering process lead time than the whole design phase lead time. A quality was seen second important factor that should be measured in projects that are designed using MDL. There, data about mistakes in different project life cycle phases were seen one solution. This is supported also in literature where Ulirich (1995) and Erickstad (2009) state that modular design platforms can reduce mistakes in drawings. Aligned with Jensen et al (2015) and Baldwin and Clark

(2000) findings about design platforms, the interviewees saw that the third important performance indicator are costs. Again, there interviewees separated costs in design phase and projects total costs. The project costs in general were seen a good indicator and reducing costs in procurement phase was a clear objective. In turn, the designing costs were seen again a problematic measure as design phase lead time. However, the design costs and lead time in design phase are still valuable data but should not be seen as an absolute objective. Fourth indicator which occurred in several interviews was the standardisation level of components. This is an interesting measure and seeking there an optimal level is important in terms of flexibility of the MDL and again the final product itself.

Development suggestions

A lead time in the design phase could be tracked but it should not be an objective. Rather a quality of designing should be the measured objective. Leadtime in construction phase is a clear measure which should be followed per square meter or per apartment. There reasonable milestones in lead time objectives is good to keep in mind. Costs in the design phase could be a good idea to measure in terms of design costs history data but reducing design costs should not be an absolute measured objective. In turn, projects general cost level and procurement cost savings could be good indicators to follow and compare to existing data from the completed projects. Moreover, the standardisation level of components could be important measurement when trying to find the optimal level of standarisation and flexibility. As a reference level for metrics could be used in 2020 completed or during two last years completed projects performance data.

6.1.6 Summary

As a summary, based on literature review and interviews, xx development suggestions were identified for Fira residential construction unit:

Modularisation strategy

- Modularisation strategy and objectives should be clarified and communicated
- System approach in modularisation strategy
- Product, process and organisational aspect should be considered equally in modularisation

Shipbuilding industry applications

- Enhanced development team which objectives to develop MDL, modules and components with suppliers
- MDL should be created mainly into design software in terms of efficient use and further complementary tools
- Stakeholders' interests should be taken into account when standardising components and developing modules into design library

Traditional supply chain towards project independent supply chain

- Procurement and MDL development team should consider together how to implement the suppliers' performance tracking in the most important modules and components
- New tasks should be identified in MDL utilisation and in module development with suppliers
- Subcontracting scopes and interfaces should be critically reviewed and mirrored with MDL

Modular design library

- Software challenges should be clearly mapped out before trying to solve them with IT-specialists
- MDL maturity steps should be described

MDL Performance tracking

- Setting performance tracking and milestone objectives:
    - Lead time in construction phase
    - Standardisation level of components
    - Quality of drawing's
    - Procurement cost savings
- Setting tracking without objectives:
    - Design lead-time
    - Design costs

6.2 Tentative strategy model suggestion

The summarised strategy model based on diagnosis is illustrated in the figure 19. The original Peltokorpi et al (2018) model is tailored based on the findings from literature and by analysing the conducted interviews. When the original model purpose was to differentiate several modularisation strategies in different construction fields, in this research created model is illustrating the strategy for Fira's residential construction modularisation. The model consists more detailed objectives and explanation for each part but those were left out from this report due the competitive advantage reasons.

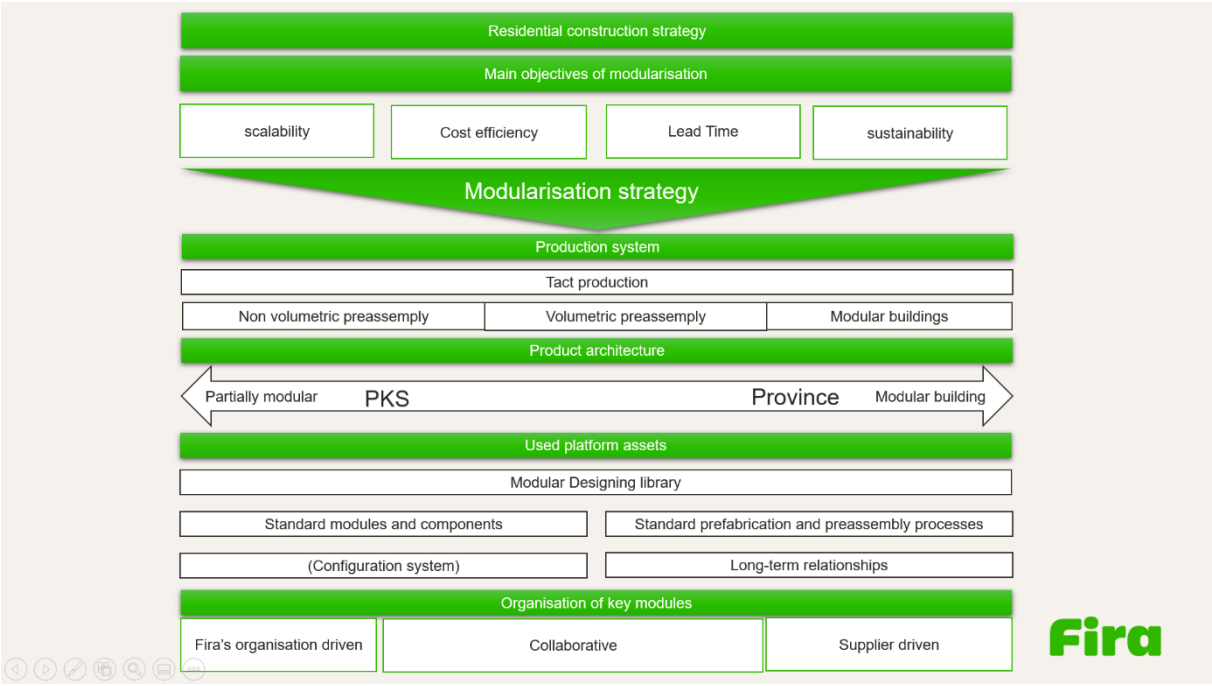


Figure 19 Tentative modularisation strategy model

The purpose of the model

As many of the interviewees underlined the significance of the connection to Fira's residential construction strategy, the modularisation strategy model main purpose is to clarify how modularity is linked to Fira's stategy, and on the other hand, what are the most important objectives for modular construction concept. Moreover, model should help to understand which are the key elements in modularisation, and what are their meanings in practice. The interviews revealed problem related to understanding modularity from different aspects. Therefore, as Peltokorpi et al (2018) argued in their study, this model strives to describe modularity from four aspect: (1) production system, (2) product, (3) platform and (4) organisation. Campagnolo and Camuffo (2010) discussed about how modularisation objectives affect to modularity. Thus, this strategy model and clarified objectives aim also to address question: how to modularise? Further development of the strategy model is presented in appendix 3.

6.3 Tentative maturity model for modular design library

The second created artifact was the maturity model for the MDL which is presented in figure 20. The model is created based on the conducted interviews with Fira's organisation and with external design consultants together with using the participating observation in several meetings and workshops concerning MDL development.

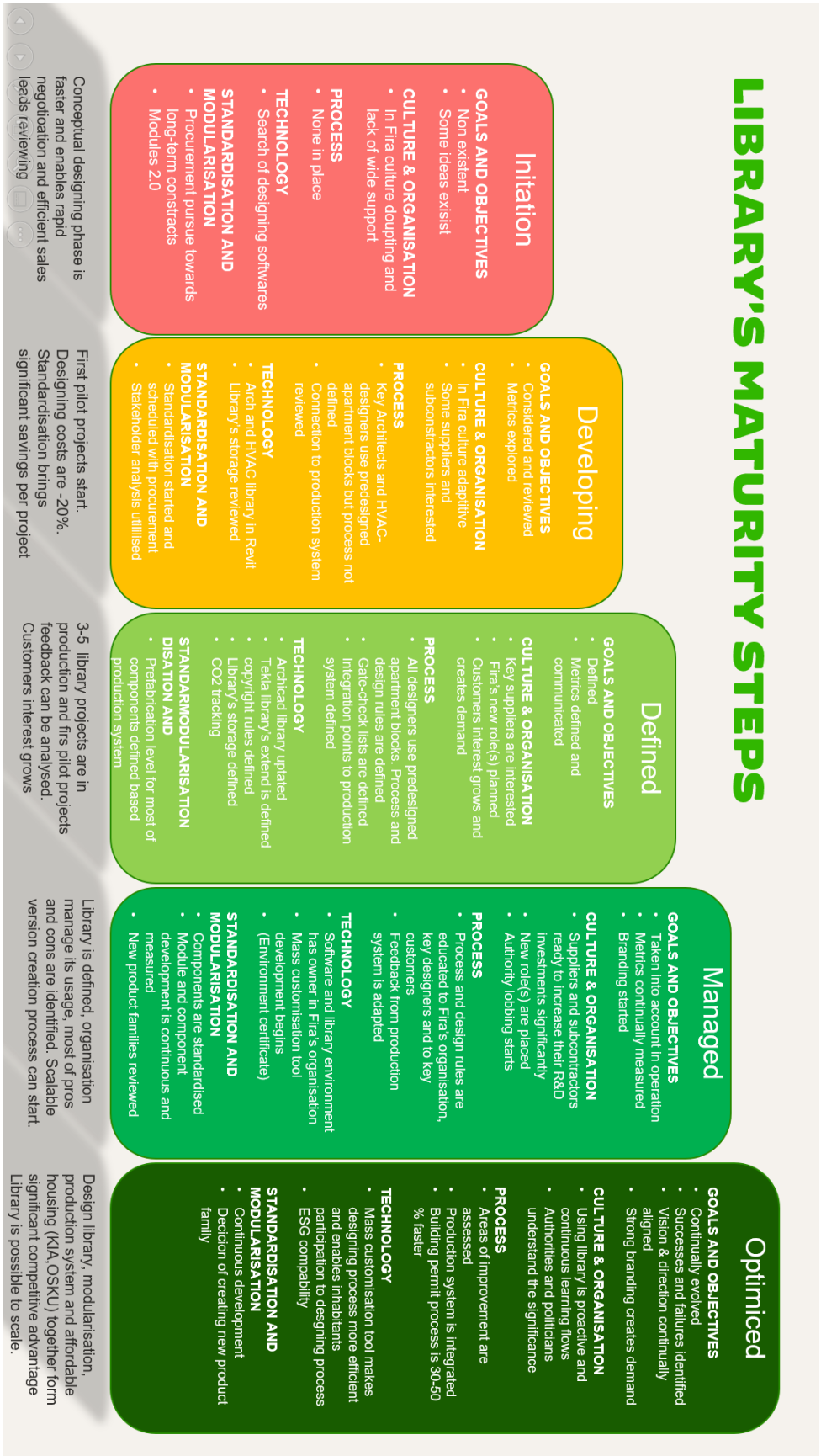


Figure 20 tentative maturity model for MDL

Purpose of model

In general, the purpose of a maturity model is to act as a framework for improving organisations results by assessing strengths and weaknesses (Ibbs, Kwak 2000). According to Kerzner (2019) there are many reasons why companies use maturity models to assess their performance, for instance: justifying investment in portfolio, program or project management improvements or gaining better understanding of their strengths and weaknesses in order to enable development to happen. In addition, maturity model can be seen as an important element in strategic planning as it acts as a roadmap to future. The link between project success and maturity model has been studied by Skulmoski (2001) who recommends view a maturity model's capabilities, skills and competences together with the project or company's performance. Maturity models are often divided in progressive maturity levels which allows organisations to plan how to reach higher maturity levels, as well as evaluate business or project outcomes at the particular level (Gomes et al. 2013). One of the most famous models is the Capability Maturity Model (CMM) developed for software developing and published in 1991. Subsequently, this model was again developed to meet other engineering fields demands and the result was Capability Maturity Model Integration (CMMI). (Gallagher 2002).

In the case company context, the purpose is to act as a measurement where Fira 's MDL development currently lies and where it should aim in the future. The maturity model in figure 20 is based on CMMI model and the maturity level is illustrated by using six different categories: 1. Goals & objectives, 2. Culture & objectives, 3. Process, 4. Technology, 5. Standardisation and modularisation, 6. Business outcomes. The maturity levels follow CMMI model five step classification. These above-mentioned aspects should help management to see what is possible when the maturity increases, and in turn, on which issues managers should focus to develop MDL by a balanced way. For instance, the software environment and content of MDL needs to be first mature enough before mass customisation tools can be implemented, or certain stakeholder groups should be educated in order to obtain full benefits of MDL. Model could also help to communicate the MDL maturity for external investors. Moreover, the maturity model can be used to estimate what parts of library are possible to scale and which are not. This is important aspect for Fira because company is rather seeking growth from service and software segments.

7 DEVELOPMENT

In this chapter the developed artifact's implementation is described. In the DSR process the testing is important part of the process. However, in this research the created artifacts modulasation strategy model and the maturity model for the MDL are difficult to test because the results will follow just after long time. Therefore, in this research the focus is more in implementing these models for Fira's management use.

7.1 Research approach

The major research method utilised in the implementation phase combines workshop style method and participating observation. The workshop method was used in the first phase of implementing the created models. Westerlund (2007) describes a works shop as an intensive method where participants' interaction plays a great role. The participants were selected according their role in MDL's development and in production system's development. The aim of workshops was to involve participants, hear their direct feedback as well as do adjustments to the created models.

At the same time the participant observation method was utilised which was defined in chapter 5.1. Furthermore, the participating observation can be divided to passive and active observation. In this research phase the active observation means that while the researcher observe he also is actively influencing to the implementation process. This method is typical for a design science research (Anttila 2006). Because the implementation of the created models require explanation from the researcher side, and on the other hand, feedback from the target groups is necessary, the active observation with the workshop approach is a sufficient method to implement created models to Fira's management's use.

7.2 Material collection and analysis

The material based on workshops and observation was collected mainly to researcher's notes. At this phase the workshops were not recorded and thus neither transcribed as were the data from interviews. In turn, the feedback from the workshops were adopted directly to the created artifacts. After the workshops these changes and notes were analysed and the created artifacts were adjusted if needed. The detailed implementation plan is presented in appendix 4. Moreover, the summary of the identified development suggestions are described and analysed in detail in the following chapters.

7.3 Implementation and results

The implementation of the modularisation strategy model and the MDL-maturity model was divided to separate workshops due the great amount of details and aspects required discussion. Moreover, the workshops concerning the MDL-maturity model were divided to three separate workshops where different stakeholders had possibility to understand the model and give explicit feedback. In turn, the strategy model workshop was decided to arrange just for the MDL steering group members.

The modularisation strategy model:
The workshop was conducted 3.12.2020 for the MDL steering group members illustrated below in table 11. The aim of workshop was to present the strategy model based on the interview research and to receive feedback from Fira's residential unit directors. Moreover, the major objective was to decide how the strategy model will be utilised in the future.

Table 11 Workshop participants

Workshop	Participant	Role	date
1	Researcher	Active observator	3.12.2020
1	Design Manager	Evaluation and feedback	3.12.2020
1	Architect	Evaluation and feedback	3.12.2020
1	Director Residential construction	Evaluation and feedback	3.12.2020
1	Head of redential development	Evaluation and feedback	3.12.2020

Feedback:

- Production system should be described better in strategy model
- How these objectives will show in MDL development? What are the targets?
- Product, process, organisation "system" approach should be illustrated in the model

Actions:

- Supply chain management was added to production system field
- MDL development team monitor objectives and agree sufficient targets in the steering group meetings
- System approach was added to model

The MDL-maturity model
As indicated in this chapter introduction the MDL model workshops were divided to three separate workshops as illustrated in table 12. The first workshop with the production system development team aimed to integrate maturity model to production system development and consider demands that the production system sets for the MDL development. The second workshop was conducted with procurement management and strived to formulate how the cooperation in component and module development should be presented in the MDL maturity model.

Table 12 Workshop participants

Workshop	Participant	Role/aspect	date
1	Researcher	Active observator	18.11.2020
1	Project manager (production system)	Production system	18.11.2020
2	Researcher	Active observator	3.12.2020
2	Design Manager	Partners/design process	3.12.2020
2	Architect	Design	3.12.2020
2	Head of redential development	Project development	3.12.2020
2	Director Residential construction	Strategic	3.12.2020
2	Director Procurement	Procurement integration	3.12.2020
2	Procurement Manager	Procurement integration	3.12.2020

Workshop 1:

Feedback:

- The structure is logical
- The data consistency and data-demands from the production system should be considered more specifically in the maturity model if possible. At least these topics should be considered in steering group meetings.
- How maturity model should be monitored from production system aspect?
- Is there more detailed plan about organisation changes?
- The metrics are good to be on this model. Is there idea what they could be?

Actions:

- Production system demands were added to *technology* and component and *module development* section. In addition, these demands will be discussed in MDL- steering group meetings and again actions will be placed then on the roadmap
- Maturity model monitoring will be organised within the MDL development and production system development teams' co-meetings.
- The suggestion considering organisation changes will be provided in the thesis presentation
- Metrics suggestions are presented in the thesis

Workshop 2:

Feedback:

- Model contains good aspects, but the question is, what are the actions to reach the next step
- How component development and cooperation with procurement should be organised?
- How library management should be organised?

Actions:

- Action plans will be made by development team and presented in steering group meetings

- MDL development team will list operational and development tasks and propose new way to divide tasks and possible new team member's duties

7.4 Summary and final concept

Based on the implementation workshop's feedback the final adjustments to the maturity- and modularisation strategy model were done. The actual changes to the both models were minor at this phase. Most of the comments in the workshops were questions about what happens next. Especially directors were interested on detailed action plans, concrete design rules and process descriptions. However, this thesis limitations were set to describe more in general level what should be done than detailed action plans for each problem. On the other hand, because these models caused discussion about these more concrete results, it can be stated that the implementation was already succeeded in that sense. Overall, these created models were seen as logic way to present modularisation and MDL development. The final models are illustrated below in figures 21, 22 and 23. The further documents related to models are presented in appendix 3 and 4.

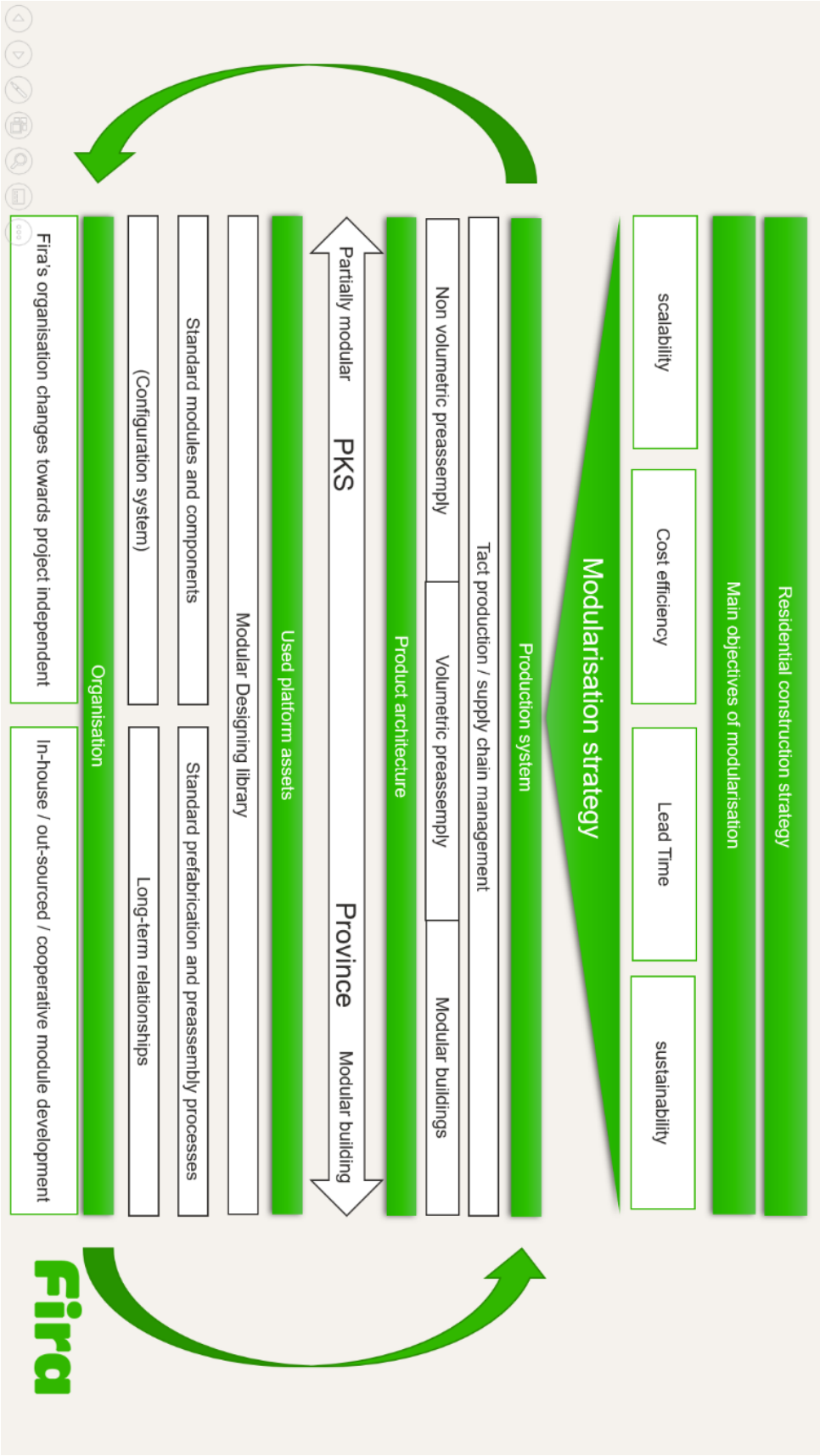


Figure 21 Final modularisation strategy model

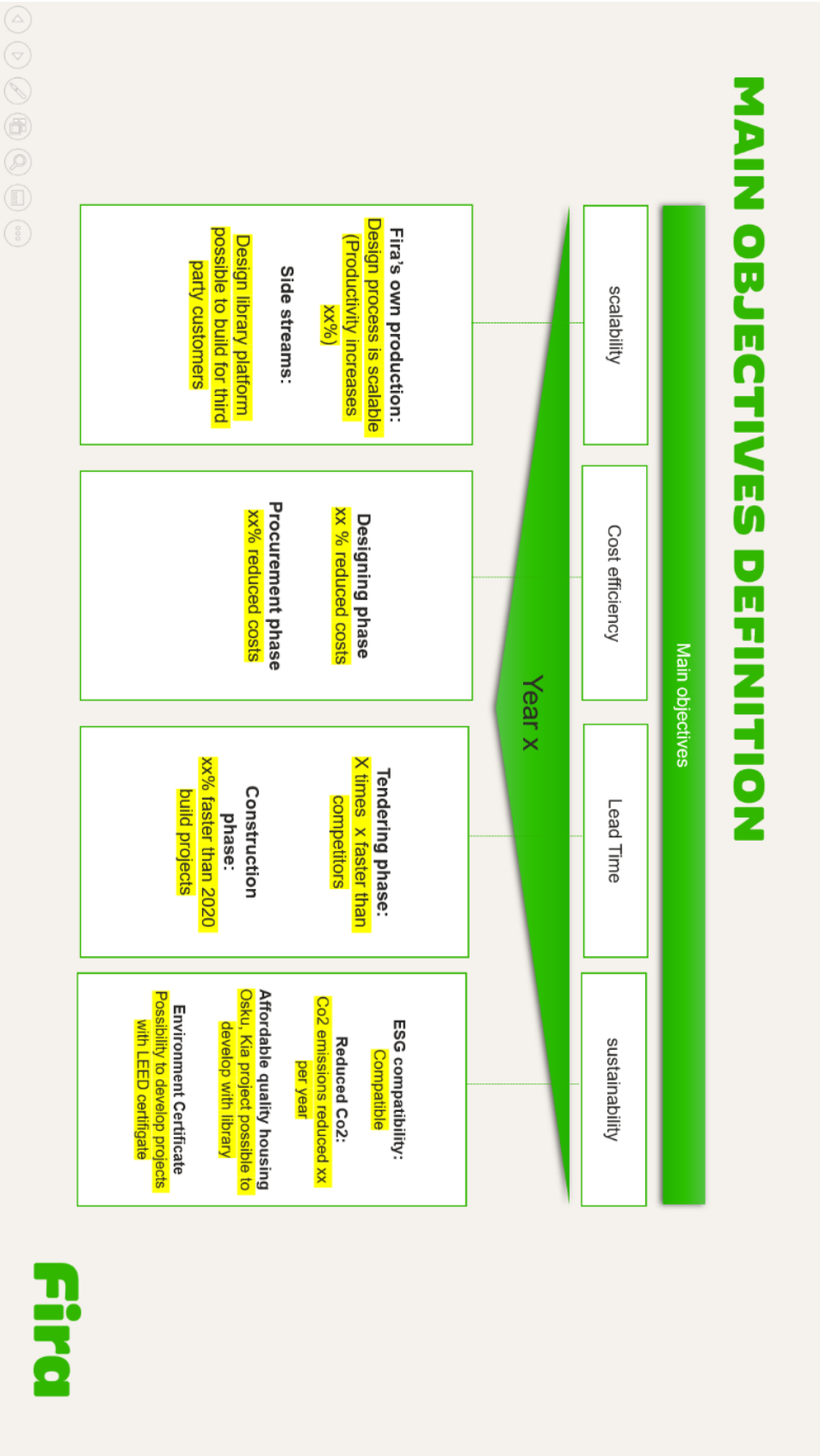


Figure 22 Final modularisation strategy model part 2

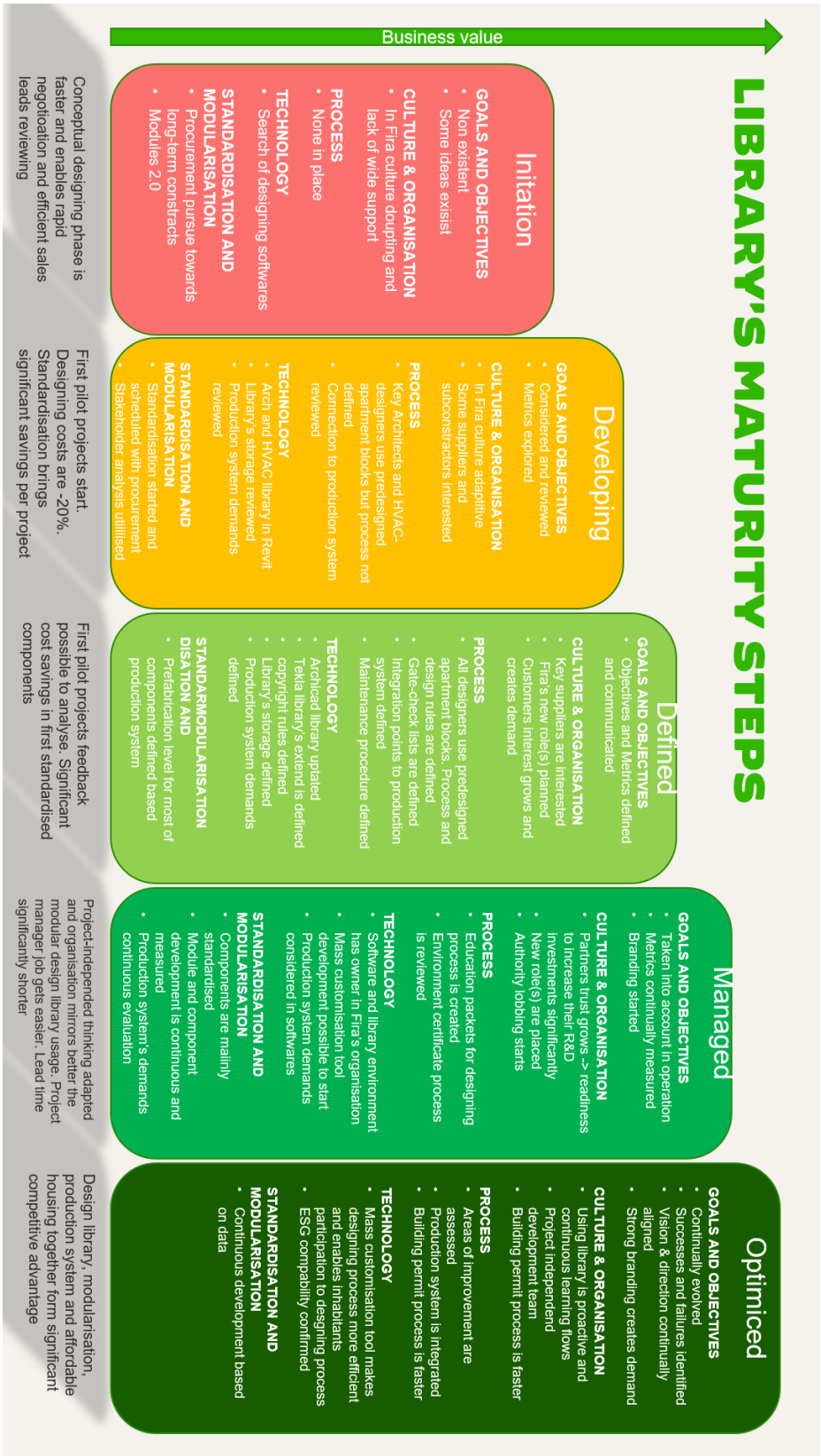


Figure 23 Final MDL-maturity model

The most important task of the strategy model is to communicate the objectives to the MDL development team and to describe all aspects in a structured way that are related to MDL development. In turn, the MDL maturity model major message is to take systematic approach to development work and to enhance Fira's organisation to make necessary organisation changes. Without allocating resources to component development, supply chain management and modular design platform management, it is difficult to achieve objectives and change construction towards more project-independent industrialised construction.

8 DISCUSSION AND SUMMARY

In this research the modular design platforms' development and the impact to traditional construction supply chain were examined. Again, characteristics of traditional construction and industrialised construction were reviewed and the development of modularisation in the ship building industry was benchmarked. The uniqueness of construction projects, fragmentation of the industry and short-term thinking have been great challenges in residential construction. In many other industries, product and design-platforms have proven to address to these problems. However, implementations in construction industry are still scarce and impacts to supply chain are not well known. Modularisation projects also tend to fail, because lack of a sufficient plan and ambiguity of the right direction. Thus, the modularisation strategy should be always composed and modularisation projects maturity steps defined.

The main objectives of this research were to find a way to clarify the strategy for modular design library project and to define its development stages with maturity model. The research was conducted as design research divided into two phases. In the first phase, the literature review was used to compose semi-structured interviews in Fira's residential unit and with external consultants. Based on the interviews, the development suggestions were presented, and tentative strategy and maturity models were formulated. In the second phase, these suggestions and models were communicated to the Fira's management and further development was made. This final chapter summarises and evaluates the research results in relation to literature review and research objectives. Moreover, the scientific contribution and the contribution for Fira's management is evaluated.

8.1 Evaluation of results

The objective of this research was addressed with three research questions (RQs) and the first represent the major research question. The first research question was formulated as follows:

How to define modular design concept and how it could change traditional residential construction towards industrialised construction?

The main RQ was reviewed in all sections of literature review. First the characteristics of traditional residential construction were defined and the major problems in residential construction supply chains were formulated. The major characteristics can be summarised as follows: construction projects uniqueness including temporary organisations, customers have great power in design process, project focused short-term thinking, fragmented industry and site production (Vrijhoef, Koskela 2005, Koskela 2000). The interview research results were mainly aligned with the findings from literature. This shows that the understanding in Fira Oy has reached level where the traditional approach is questioned, and company strives to change the practices in the industry. In literature, various studies show that modularity and modular product platforms could be the answer, at least in some extent, in construction industrialisation.

Modularity and modular product platforms are argued to: ease standardisation of components but still maintain the flexibility with mass customisation tools (Jensen, et al. 2015, Erikstad 2009), to offer more stable view to business and longer production series for suppliers (Erikstad 2019), reduce complexity and enable offsite fabrication practices (Voordijk et al. 2006). All these factors are characteristic for industrialised production as Girmcheid (2015) summarised. Therefore, modular product platforms and modularisation in general can be seen to have a connection with industrialised construction. Also, the interviews with Fira's organisation and external consultants revealed that the interviewees hold similar view of benefits as authors in literature review argued. More unclear for interviewees was how the modularisation and modular design library should be developed and what kind of impact that would have to Fira's organisation and production system. Thus, the modularisation strategy model and MDL maturity model were created to address this uncertainty and to give clearer direction. Fira has taken modularity in its main strategy but it is not discussed in detail with the organisation. The findings in literature and in interviews with the ship building industry suggest that modularity should be equally reviewed from three different aspects: product, process and organisation. Furthermore, these aspects should mirror each other. (Campagnolo, Camuffo 2010). On the other hand, interviews with Fira's organisation revealed that there is lack of mirroring modularity in respect to the organisation and processes. Therefore, these aspects are considered in the created strategy model and in maturity model. In practice, these aspects should be considered in the becoming steering group meetings.

Perhaps the most important finding of this research was that modular design platforms and standarisation of its components could enable changing the mindset from project-focused towards project-independent industrialised thinking in construction. When authors such as Aapaoja and Haapasalo (2014), Vrijhoef and Koskela (2005), Campagnolo and Camuffo (2010) supported this claim, interviews with Fira's organisation and external consultants showed that this idea is slowly spreading in construction industry but requires still a lot of work. The change project-focused towards project independent thinking could enable great benefits such as a deeper relationship with partners, enable an efficient usage of partner network's R&D capacity, better learning and project-independent development. In addition, design platforms and standardisation of components could enable the development of industrialised production system.

The second RQ

How modularisation has impacted to the ship building industry and how best practices could be implemented in the residential construction?

The second RQ was reviewed in literature review's chapter 3.3 and in addition the interview was conducted with Finnish shipyard Meyer Turku's modularisation team. The literature review focused mainly Norwegian professor Stein Ove Erikstad's studies concerning Norwegian shipyard Ulstein in 2009 and 2019. Especially, these studies showed how Ulstein shipyard is a forerunner adapting a modular product platform and modular ship architecture in

the ship building industry. When the traditional ship building focuses on individual projects, the new approach enhances more developing and maintaining a project independent product platform which is then exploited in individual projects. This shift towards project-independent product platform is based on studies which show that allocating more resources for modularisation and platform development is expected to provide benefits in the exploitation phase, or in other words design and production phase. Some of these benefits are argued to be as: faster tendering process, efficient design phase with high quality drawings and shorter lead time in the production phase. All these are aspects that improve a shipyard productivity. From the supply chain and market perspective, Erikstad (2019) and Halse (2014) argued that interfaces will have impact to various aspects. For instance, modular ship architecture with clear module has enabled utilising flexible global supply chains and outsource some activities to shipyards with lower labor costs. Moreover, the product platform and standardisation are argued to enable local partners to lower their production costs due the longer production series. Standardised components and modules seems to also have impact to suppliers increased R&D investements. In the market level product platform should shift power in specification decisions from customers towards shipyard.

The interview with Meyer Turku's shipyard revealed that similar steps have been taken as was in the Ulstein case in literature review. First, the establishment of modularisation team with five members show that modularisation is strongly enhanced in Meyer Turku's strategy. Setting up a new team corresponds with the findings in literature which argued modularity should be also mirrored to organisation. Second, the team has started to develop a modular design platform or modular design library as they called it. According to interviewees, a modular design library, standardisation and long-term cooperation with supplier's has increased the suppliers will to invest R&D and manufacture prefabricated modules. This activity had already provided good results in production lead time and improved productivity. Third, the interview revealed that for efficient use and in terms of future's add on applications, design library should be built into design software and support 3d designing. In the market level Meyer Turku's modularisation specialists saw slow change in decision power, shifting from customers to shipyard, but mostly in technical solutions. While the modularity could enable usage of global supply chains, this option was not highly used due the shipyard's strategic choices.

These findings could encourage Fira to do changes in their organisation in respect to gain better results with their modularity strategy. Moreover, Fira could establish teams with suppliers to make deeper cooperation and find faster solutions that meet Fira's objectives. Even sending Fira's organisation members to supplier's offices for longer time could be one idea to create deeper trust and enhance suppliers to invest more to R&D projects. On the other hand, flexible global supply chains are perhaps not a great chance for Fira. The power balance in the specification decisions is definitely the point, that Fira should focus on, because this is important in respect to standardisation and industrialised production system. This can be really challenging, because at the same time a flexibility and stakeholder's interests should be considered. Finally, aligned with Campagnolo and Camuffo (2010) and Baldwin and Clark

(2000) the core message from ship building industry were basically as follows: product, organisation and process aspects should be considered equally, and stakeholder's interests should be carefully taken into account in modular design library development, standardisation and module development.

The third RQ

How stakeholder's interests should be considered in modular design library's development and how development steps should be defined and tracked?

The third research question was reviewed mainly in chapter 3.2 and in the interviews with Fira's organisation and external design consultants. In literature, stakeholder's interests in respect to modularity are classified by Baldwin and Clark (2000) to three different domains: Modularity-in-Design (MID), Modularity-in-Production (MIP) and Modularity-in-Use (MIU). This classification could be also valuable for Fira when it does module development with its partners or in its own module development. Which stakeholders belong to the particular group, and again what are their interests, are the important questions. The interviews exploited this classification and the interviewees from the different stakeholder groups were interviewed. Although, because of this study limitations the "modularity in use" aspect was left for smaller focus in this research. The interview's answers show that we can clearly see designer's interests differentiate from Fira's project managers and production director's interests. For instance, when designers were worried about their design tools copy rights, Fira's organisation was more worried about the modular design library content's copyrights. However, even the stakeholder's interests were different, four major interests in modular design library development can be recognised: software technical functionality, copyright matters, designer's responsibilities and library's maintenance. Of course, stakeholders also have economic interests and that factor should be considered fairly. In practice, designers and suppliers who participate to long-term development should be treated in way that they benefit as well.

The participating observation and interviews revealed that there is a lack of documentation and lack of clear plan, which have obstructed efficient development of MDL. Therefore, the MDL-maturity model was created as a part of this research. First, with the classification of the MDL-maturity model Fira can better assess the current state of MDL project and use it as a tool when creating plans to increase the maturity in different areas. The software environment and copy rights can be already identified to be left behind from development. Therefore, the design software problems need a structured approach and well documented questions and objectives before IT-specialists can participate to the problem-solving process. Secondly, well designed maturity steps could bring in general clarity to development process and facilitate communication about MDL in Fira's organisation and to other stakeholders. A better definition of MDL could also help to increase interest among Fira's partners towards MDL.

Aligned with Skulmoski (2001) the MDL-maturity model needs to be assessed with the performance metrics of the project. The corresponding performance metrics were suggested in

chapter 6.1.5. The literature review and the interviews indicate that the most important performance metrics could be related to strategy model's major objectives: project lead time, costs, and sustainability. Also, the tendering and design process' lead time and quality are aspects that should be considered simultaneously with maturity MDL steps.

8.2 Evaluation of scientific contribution

The literature review indicated that even the usage of modular design platforms in many manufacture industries has been successful, the implementations in residential construction are still rare (Jansson et al. 2014). Moreover, the research about how modular design platforms should be seen as a part of construction industrialisation is still minor, and there is lack of knowledge how modular design platforms impact in different domains of construction. Therefore, this research's first main scientific contribution is to provide few ideas how modular design platforms could make a significant change in thinking in construction industry. By compiling literature findings and two similar industries' (ship building and residential construction) interview's results, the change towards project-independent thinking was identified and again discussed in detail from the perspective of residential construction.

The second scientific contribution is the MDL-maturity model. The model was explicitly created for Fira but could at the same time represent a useful structure in more general level. The maturity model could help other construction companies who are planning to create modular design libraries in the future, to see possible development steps and a direction. On the other hand, the created maturity steps could also help researchers to study subject in a structured way.

The narrow stakeholder analysis concerning modular design library's developing process could be seen as a third scientific contribution. Although, the stakeholder analysis was very limited, it provides still a useful information for companies who are starting the modular design platform development process. The analysis gathers together important stake holder's interests and possible significant challenges during the MDL development process.

8.3 Managerial implications

Apart from the scientific contribution of this thesis, the aim was to solve the problems related to Fira's strategy implementation. In the big picture Fira's aim is to improve productivity and shorten the construction lead time by implementing production system that exploits takt scheduling, digital management tools and modularity. Fira has earlier started the modular design library project but the development required clear goals and development steps. In addition, Fira's management needed a view how MDL could impact on Fira's organisation. The research strived to bring more clarity in these matters by reviewing literature and interviewing different stakeholders in residential construction, in the Fira's organisation and in external

design consultant's organisations. Moreover, to have a broader view, the modularisation specialists in Finish ship building industry were interviewed and possible applications to construction industry were analysed.

Based on the above-mentioned aspects, the Fira's MDL development project's current situation was able to be identified and focused development suggestions were possible to be formulated. In addition to development suggestions, the first major contribution for Fira's management is the created modularisation starategy model that helps to clarify modularisation objectives, and moreover differentiate what these objectives mean in different domains. In addition, the created strategy model could be utilised to communicate Fira's modularisation strategy to other stakeholder groups such as: partners, clients and possible investors. Also, possible impacts to the Fira's organisation and the supply chain were identified and discussed. The second major contribution is the created maturity model for the MDL, which again helps Fira's management to see development steps and direction of the MDL project. Moreover, the model helps to monitor the situation and to plan future steps in the steering group meetings. Again, the model can be used to communicate the MDL project status to Fira's board and possible investors. Finally, the possible metrics were identified for future projects that will be designed by utilising MDL. These metrics can help Fira's management to monitor how the projects performance improves in the construction projects where MDL is implemented.

The major objective of this research from Fira's management perspective was to bring a clarity how the MDL could change traditional construction towards industrialised construction. The research results and created models answer to the question how, and therefore it can be stated that the objective is achieved in some extent. Because the pilot projects feedback was not possible to include to this research, the final benefits of this research will reveal in following years.

8.4 Limitations and sources for error

This chapter aims to test the reliability of the whole research. The most remarkable limitations and the sources for errors are related to research methodology, the role of the researcher and the selection of the subject. Again, limitations and sources for error can be classified to two different groups; validity and reliability.

Hirsjärvi et al. ((Hirsjärvi, S. et al. 2014) indicates that validity refers to the research ability to measure exactly that phenomenon which is the subject of the study, or in other words, the objective of the research is achieved by utilising the sufficient method. Several aspects can affect to research's validity. For instance, if the researcher asks wrong questions or interpretation consist errors as well as if the interviewees may not understand the researcher's questions, the research validity is decreased. In the qualitative research, the validity is possible to increase with accurately described research process (Janesick 2020) . In turn, a reliability

refers to the research repeatability, or in other words how replicable the obtained results are Hirsjärvi et al (2014). The reliability can be improved by detailed description how the research was executed (Janesick 2020).

Kiviniemi (2015) suggests that Design Research validity can be evaluated through three criteria: process validity, practical validity and generalisability. *Process validity* refers to how well the process has been described and how consistently it has been followed. Even the DSR process and research plan were well described in detail, the research did not follow completely the original plan. In the middle way the research questions needed to be redefined. The researcher himself suggested changes based on his findings and analysis. Otherwise, the research followed the original plan and process. The research was conducted mainly alone and therefore outside supervision played minor role. On the other hand, the researcher conducted several meetings with the MDL steering group and with the research mentors, so in some extent the research steps were evaluated. Moreover, utilisation of various research methods increases the reliability of obtained results.

Practical validity evaluates how well the created artifact or model serves the objective from practical perspective. The modularisation strategy model and MDL-maturity model brought clarity and structure to Fira's modularisation strategy and MDL-development process, thus it can be stated that it served the objective also from practical perspective. The strategy model's creation process could have included more stakeholder interviews, and competitor analysis but it was not possible due the limitations of this thesis. The suggested metrics for MDL-projects were evaluated to be sufficient.

Generalisability means how well the created model is possible to generialise to other contexts. The created modularisation strategy model must be always contextualised so the generalisability is not at very high level. On the other hand, the model could be easily contextualised for Fira's other business unit. The MDL-maturity model also is highly explicit tool, but in some extent, it can be used in other companies as a guideline for modular design platform creation.

Furthermore, the semi-structured interviews also bear some limitations to the research. First the researcher subjectivity can impact to the results, on the other hand, the researcher did not work in the company during the research which gave more objective approach. Second, the researcher inexperience in semi-structured interviews and in general in the research process can increase the possibility for wrong conclusions. On the other hand, the researcher's experience from the construction industry helped with the literature review to formulate sufficient interview questions, which were evaluated after every interview. Also, the experience from the case company Fira helped to find easily the expedient people for the interviews. Moreover, almost all interviews were recorded, and transcriptions were conducted by external company which are all factors that increased the reliability and decreased the risk of subjectivity. (Mills et al. 1987) To summarise, given the above considerations, it can be stated that the research validity

is at a good level. In turn, reliability cannot have as good grade because of redefined research questions during the process and due to many aspects, that increase subjectivity.

8.5 Conclusion and possibilities for future research

In this research the modularisation strategies and modular design platforms were reviewed and studied how these could change traditional construction towards industrial construction. The modularisation strategy model and modular design library's maturity model were created and implemented. In this chapter the results of the research are finally summarised to conclusions and possibilities for future research are presented.

The short-term project-based thinking and unique projects together with fragmented industry are the some of the greatest problems that causes a low productivity and obstruct quality improvements in the residential construction industry compared to industrialised manufacture industries. This discontinuity across projects leads to vicious circle of optimisation in short-term and lack of trust to make long-term research and development investments in construction supply chains. Again, uniqueness in design processes leads to lack of cumulative learning in both design and production phase.

Standardisation of components and modularisation can decrease the uniqueness across the projects, but if the design process always starts from the beginning the variation between projects may remain at a high level because of subjective opinions and choices during the design process. Therefore, construction companies should invest to modular design platforms that utilise predesigned apartments and modules. Implementing a modular design platform can provide continuity across the projects by increased standardisation and modularisation in building components. The above-mentioned aspects can lead to deeper relationships with the suppliers and sub-contractors who are interested about long-term development. In the big picture fragmented industry could change less fragmented when suppliers and subcontractors are enhanced to invest research and development and grow. On the other hand, modular design platforms can shift the power balance in design decisions more from the clients towards construction companies while still offering variations with mass customisation.

Nevertheless, the successful implementations of modularity theories and modular design platforms in construction industry are still scarce. The successful implementation is a long and complex process where modularisation strategy and objectives play important roles. Moreover, the development of a modular design platforms should be considered in a balanced way in three important domains; product, process, and organisation. Important is to design how the modular design platform and product architecture are integrated to production system. On the other hand, the modular design platform and module development can raise pressure to make changes traditionally highly project-based organisation structure. In practice, this means that companies should consider allocating more resources to project-independent component and module

development and to maintaining the modular design platform. Moreover, the component and module development should be based on data and on set targets. This change has happened in many manufacturing industries and currently it is happening in the ship building industries in Norway and in Finland.

Modularity and modular design platforms should be seen as important elements in the change from traditional residential construction towards industrialised residential construction. This shift will have a greater chance to succeed by composing a modularisation strategy, and by designing development steps as well as paying attention on the integration with production system.

The identified possibilities for future research are:

1. **Modular design platform integration to production system:** This research revealed a need for further study how production system should be integrated with modular design platform. This is already partly considered by cross-meetings with different development teams, but the knowledge there is still minor.

2. **Modular design platform scalability:** The original idea of this research was to review how Fira's modular design library could be scaled and sold as a service for external construction companies. However, because the development of modular design library was in the beginning and there wasn't a clear plan, it was too early to examine scalability possibilities. Now when there is a clearer plan and the development has achieved important milestones, the scalability study could be possible to conduct.

3. **Modular design platform projects performance compared to conventional projects:** One of this research limitations was to get feedback from the pilot projects. Therefore, one interesting topic for future research could be a case study which would compare traditional projects and projects produced with the modular design library. In addition, the modular design library development costs should be considered to find how long it takes to obtain breakeven point.

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Appendices

Appendix 1: Semi-structured theme interview structure

First question: Do you think you can contribute to these questions?

1. **Introduction, position and background of the interviewee**

    a) How long you have been working at Fira / in your current position?
    b) How you understand modular designing and production? How you see the current situation in Finland?
    c) How do you see the current level of modularisation at Fira? What modules Fira is using in its residential construction production?

2. **Modularisation strategy and new scalable business models (major research question)**

    a) Does Fira have defined modularisation strategy? Do you think that it is important to compose the strategy?

    b) What are the most important objectives for modularisation of the residential production and their priority? Can you describe what do these objectives mean?

        i. High quality
        ii. Innovative design
        iii. cost efficiency
        iv. design and construction lead time
        v. scalability
        vi. Sustainability
        vii. Some other objective? What?

    c) Who are the major modular construction competitors in Finland and what could be Fira's competitive advantage?

    d) What could be the major customers segments in terms of modular building production?

    e) What could be the benefits for the major stakeholders?

        i. Contractor
        ii. Institutional customers
        iii. End customers
        iv. suppliers
        v. Offici

f) How do you see the current level of Fira Oy's residential construction modularity and where it should be in terms of modularisation objectives?

g) How do you understand scalable business models, and could modularisation help to create new scalable businesses?

   i. In Fira's own product family
   ii. Selling services outside
   iii. Royalties

3. Traditional residential construction supply chain and the shift towards modular supply chain (1. sub-question)

a) In general, what are the major characteristics that cause a low productivity in residential construction?

   I. Describe Fira's supplier network and supply chain management. What could be the characteristics that obstruct the productivity improvements?

   II. What is the share of project-dependent procurement and how much there is co-operative development with suppliers?

b) How the platform and the module approach could address to these problems and how they would change the supply chain?

   I. What kind of collaboration with module manufacturers could achieve lower costs and better flow in the production?
   II. Should Fira have an ownership in other key modules than the bathroom module?

c) Modularisation and platform approach may set demands for redefining the organisation structure. Do you think that the new roles such as "Platform manager" and "module manager" is needed?

   I. What kind of skills this role would emphasise?
   II. For who this position would report?

4. Modular construction concept competitive factors in terms of scalable business models (sub-question 3)

a) What Fira's modularisation strategy objectives could create a base (lead time, innovative design process, etc) that would support scalable business models?

b) Does Fira have know-how

5. Modularisation of ship building industry (2. sub-question)

a) Can you describe what are the most important changes in last 10-20 years in the shipyards supply chains?

I. Has modularisation reduced number of suppliers and have key suppliers grown bigger?
II. Does finish shipyards use global supply chains and in what extend?

b) Are you using design libraries or design platforms? If so, can you describe how you utilise them in ship designing?

I. Are you using in house- or external designers?
II. Are modules design shipyard or supplier driven?

6. Modular designing library roadmap (second major research question and sub-questions)

a) What factors should be considered during the development and implementation the modular design library?

I. Modular design library, how to share the library and without losing competitive benefits

b) what kind of performance measures should be placed to observe utilisation of the modular design library?

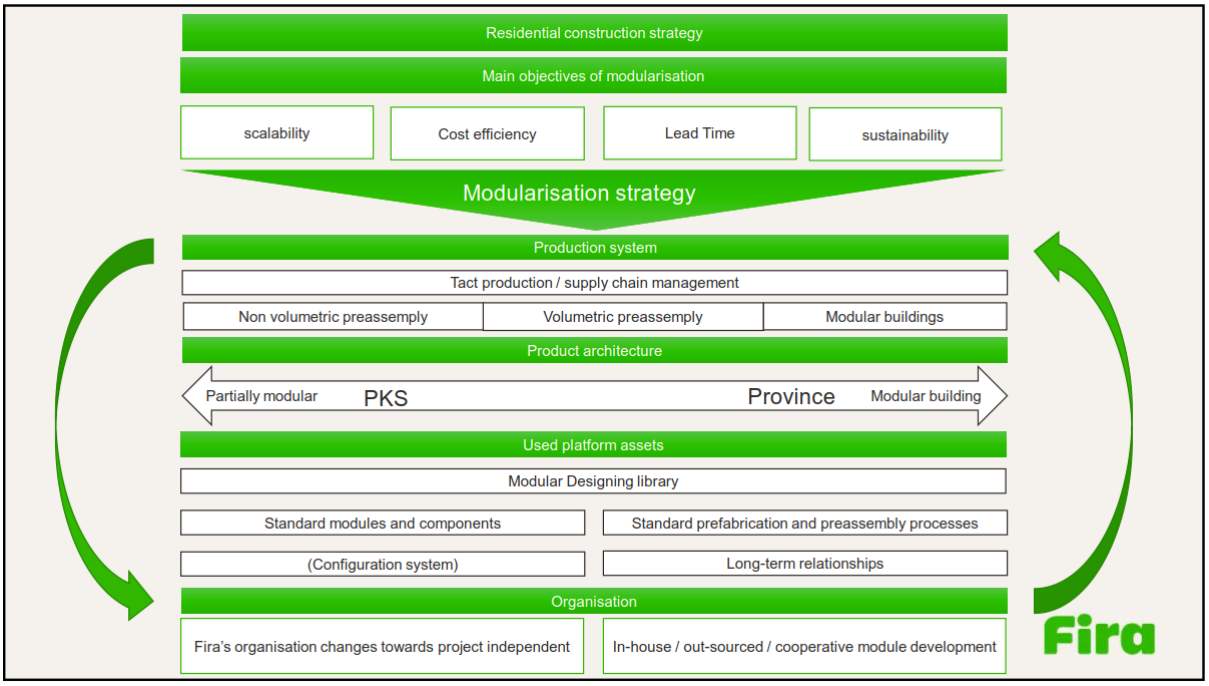
7. Free discussion, end

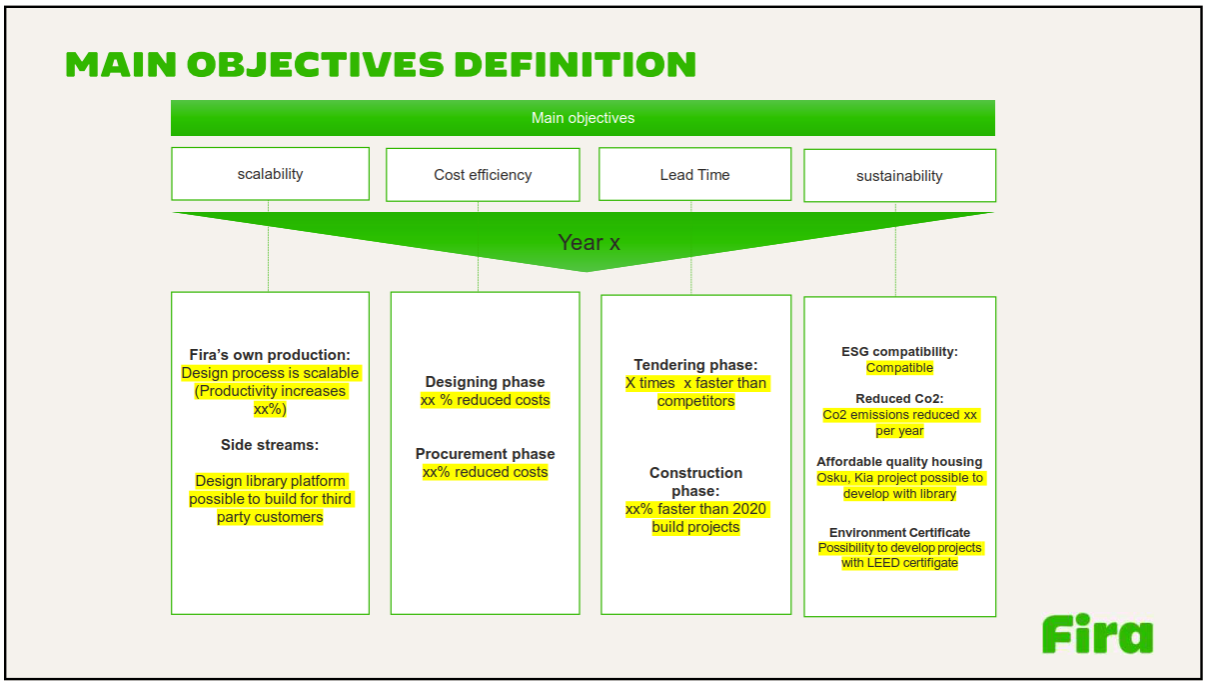
a) Do you have some other aspects that you would like to discuss?

b) Do you think that the clarification of modularisation strategy is necessary and focus of this research is appropriate?

c) Who else do you think I should interview?

Appendix 2: Modularisation strategy model

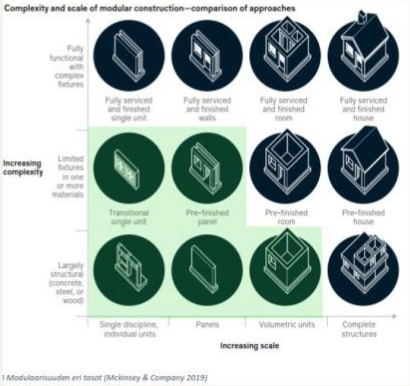




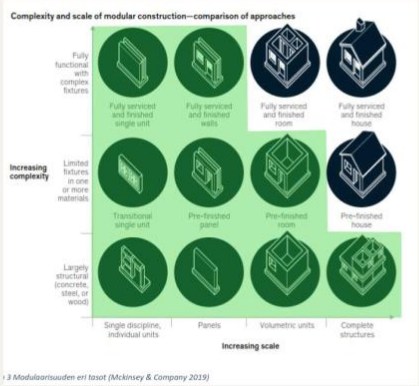
Product architecture

Partially modular ⟷ Modular building

PKS: Concrete construction



Provinces: Wooden modular buildings



Fira

PROJECT ORGANISATION TOWARDS MODULAR ORGANISATION

Case Meyer Turku

New five person modularisation team:
- (Modularisation project manager, Modularisation manager, Modularisation specialist, Head of modularisation, Library engineer)

Main mission:
Influence stakeholders thinking and educate them to understand benefits of modularity and build a modular design library

Case Fira

Key module manager(s):
- Component & module development with suppliers
- Faster flow at site
- Component & Module prices down
- (Under procurement?)

Platform engineer/manager:
- Design library admin
- DL maintenance
- A Link between module manager, procurement and RD

First step

Two or three person team:
- Design manager
- Modularisation specialist
- Design library owner/manager

Before:
3 x 5000asm2 projects/a per project manager

→ **With library:**
4x 5000asm2 projects/a per project manager

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MODULES AND COMPONENTS

Multi-project level modules?

- Bathroom module
- Balconies
- Kitchen
- Air-raid shelter

Multi-project level components?

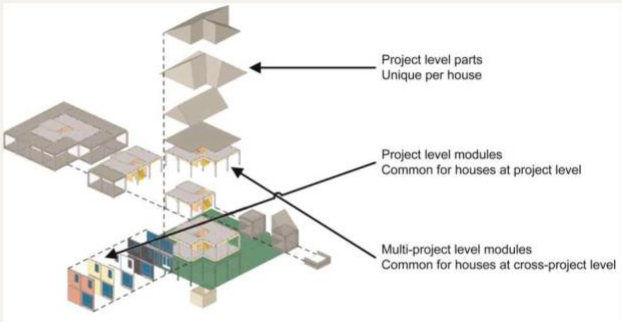
- Apartment wall elements and slabs

Project level modules?

- HVAC- room modules

What are the unique project level components?

- First and top floor wall elements and slabs
- Roof elements



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MODULAR DESIGN LIBRARY

Esisuunnitellut asuunnot ja kerrostalot:

- ARK-asuntoblokit (400kpl)
  - TATE asuntoblokit
  - RAK asuntoblokit

Ohjelmistot ja työkalut:

- ARK-kirjasto Revit
- Natiivikirjasto BIM 360
  - Tate-Kirjasto Revit
  - RAK-kirjasto Tekla
- Rekisterinhallintatyökalu
  - Konfiguraattori

Vakioidut komponentit ja moduulit:

- Toimittajan tarkat suunnitelmat
  - Vakioitu:
    - Modules
    - Keittiöt
    - Portaat
    - Ikkunat

Säännöt:

- Suunnittelusäännöt
  - ✓ Rakenneselostus
  - ✓ Rakennetyypit ja detaljit
- Gate-vaatimukset
- Asennusohjeet

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Appendix 3 (1/2)

LIBRARY'S MATURITY STEPS

Business value

Initation

GOALS AND OBJECTIVES
- Non existent
- Some ideas exisist

CULTURE & ORGANISATION
- In Fira culture doupting and lack of wide support

PROCESS
- None in place

TECHNOLOGY
- Search of designing softwares

STANDARDISATION AND MODULARISATION
- Procurement pursue towards long-term constracts
- Modules 2.0

Conceptual designing phase is faster and enables rapid negotioation and efficient sales leads reviewing

Developing

GOALS AND OBJECTIVES
- Considered and reviewed
- Metrics explored

CULTURE & ORGANISATION
- In Fira culture adaptitive
- Some suppliers and subconstractors interested

PROCESS
- Key Architects and HVAC-designers use predesigned apartment blocks but process not defined
- Connection to production system reviewed

TECHNOLOGY
- Arch and HVAC library in Revit
- Library's storage reviewed
- Production system demands reviewed

STANDARDISATION AND MODULARISATION
- Standardisation started and scheduled with procurement
- Stakeholder analysis utililised

First pilot projects start. Designing costs are -20%. Standardisation brings significant savings per project

Defined

GOALS AND OBJECTIVES
- Objectives and Metrics defined and communicated

CULTURE & ORGANISATION
- Key suppliers are interested
- Fira's new role(s) planned
- Customers interest grows and creates demand

PROCESS
- All designers use predesigned apartment blocks. Process and design rules are defined
- Gate-check lists are defined
- Integration points to production system defined
- Maintenance procedure defined

TECHNOLOGY
- Archicad library uptated
- Tekla library's extend is defined
- copyright rules defined
- Library's storage defined
- Production system demands defined

STANDARMODULARISATION DISATION AND
- Prefabrication level for most of components defined based production system

First pilot projects feedback possible to analyse. Significant cost savings in first standardised components

Managed

GOALS AND OBJECTIVES
- Taken into account in operation
- Metrics continually measured
- Branding started

CULTURE & ORGANISATION
- Partners trust grows -> readiness to increase their R&D investments significantly
- New role(s) are placed
- Authority lobbing starts

PROCESS
- Education packets for designing process is created
- Environment certificate process is reviewed

TECHNOLOGY
- Software and library environment has owner in Fira's organisation
- Mass customisation tool development possible to start
- Production system demands considered in softwares

STANDARDISATION AND MODULARISATION
- Components are maiinly standardised
- Module and component development is continuous and measured
- Production system's demands continuous evaluation

Project-independed thinking adapted and organisation mirrors better the modular design library usage. Project manager job gets easier. Lead time significantly shorter

Optimiced

GOALS AND OBJECTIVES
- Continually evolved
- Successes and failures identified
- Vision & direction continually aligned
- Strong branding creates demand

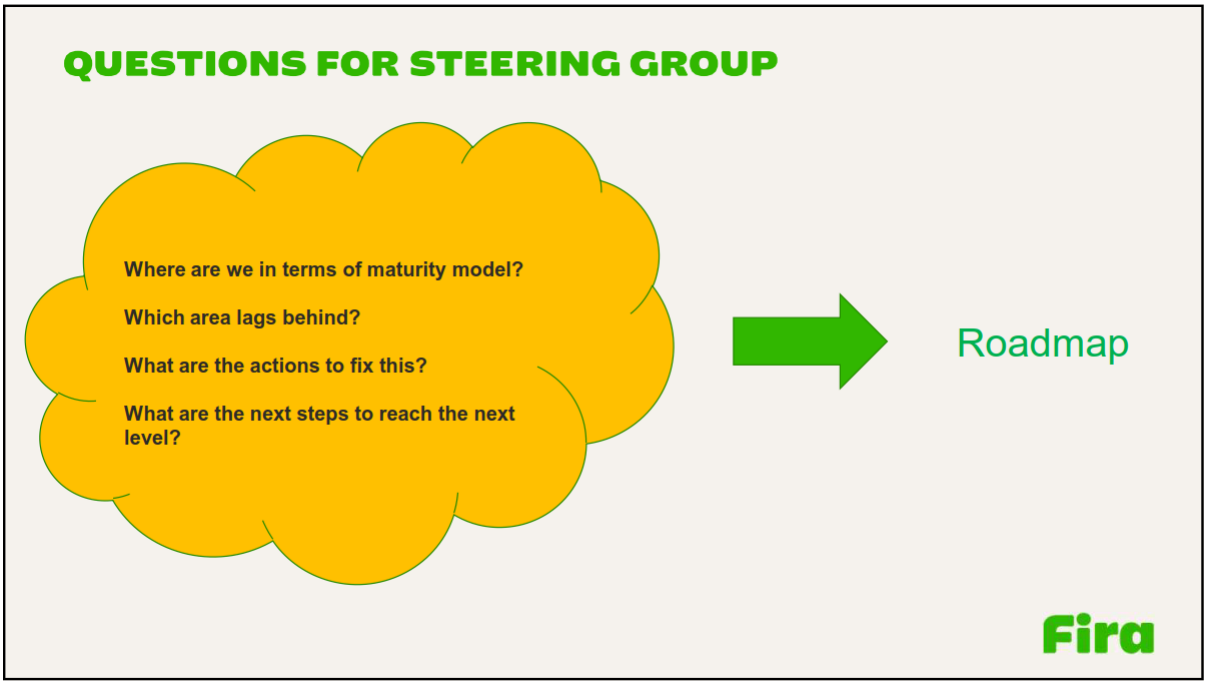
CULTURE & ORGANISATION
- Using library is proactive and continuous learning flows
- Project independend development team
- Building permit process is faster

PROCESS
- Areas of improvement are assessed
- Production system is integrated
- Building permit process is faster

TECHNOLOGY
- Mass customisation tool makes designing process more efficient and enables inhabitants participation to desgning process
- ESG compability confirmed

STANDARDISATION AND MODULARISATION
- Continuous development based on data

Design library, modularisation, production system and affordable housing together form significant competitive advantage


QUESTIONS FOR STEERING GROUP
Where are we in terms of maturity model?
Which area lags behind?
What are the actions to fix this?
What are the next steps to reach the next level?
Roadmap
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1

JALKAUTUSSUUNNITELMA

- **Mitä jalkautetaan?**
  - Maturiteettimalli
  - Modularisaatiostrategiamalli
- **Kenelle jalkautetaan?**
  - Asuntokirjaston ohjausryhmälle (Topi L, Santtu H, Tero V)
  - Tuotantosysteemin kehitysryhmälle (Ville Väätäjä, Otto Aihava)
  - Hankinta (Mikko Anttila, Rami Sariola)
  - Asuntolinja
- **Miten jalkautetaan?**
  - Workshop 1 (Esitellään tuotantosysteemin kehitysryhmälle ja integroidaan tarvittavat liittymäpinnat maturiteettimallin)
  - Workshop 2 (Esitellään maturiteettimalli hankinnalle ja integroidaan tarvittavat liittymäpinnat)
  - Workshop 3 (Esitellään maturiteettimalli Asuntokirjaston ohjausryhmälle ja huomioidaan viimeiset kommentit)
  - Workshop 4 (modularisaatiostrategiamallin esittely asuntokirjaston laajennetulle ohjausryhmälle ja huomioidaan viimeiset kommentit)
  - Diplomityön lopullinen esitys (esitetään asuntolinjassa työn hedelmät)
  - Maturiteettimallin säännöllinen läpikäynti kuukausittain Asuntokirjaston ohjausryhmässä ja tuotantosysteemin integrointipalavereissa
  - Strategiamallin puolivuosittainen läpikäynti asuntokirjaston ohjausryhmässä/asuntolinjassa
- **Koska jalkautetaan?**
  - Workshop 1 18.11.2020
  - Workshop 2 vk 51
  - Workshop 3 3.12.2020
  - Workshop 4 vk 52 / 53
  - Loppuesitys tammikuu 2021

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2

WORKSHOP 1 18.11.2020

- **Osallistujat**
  - Juha Eloranta (diplomityöntekijä)
  - Ville Väätäjä (tuotantosysteemin kehitys)
- **Aihe**
  - Asuntokirjaston maturiteettimallin jalkautus ja integrointi tuotantosysteemiin
- **Huomiot**
  - Jaottelu looginen
  - Tuotantosysteemin integrointi (tiedon "valuminen" tuotantosysteemiin) otettava tarkemmin huomioon, erityisesti mitä dataa tuotantosysteemi tarvitsee pitäisi huomioida asuntokirjaston suunnitelmissa ja ohjelmistoissa.
  - Miten maturiteettimallia seurataan tuotantosysteemin näkökulmasta?
  - Miten organisaation muuttuminen huomioidaan?
  - Onko mittareista ollut keskustelua?
- **Jatkotoimenpiteet**
  - Tuotantosysteemin integroituminen lisätään maturiteettimallin teknologia osioon ja tarkempi sisältö pohditaan asuntokirjaston ohjausryhmässä → jatkotoimenpiteet jalostetaan roadmappiin
  - Maturiteettimallin seuraus tuotantosysteemin ja asuntokirjaston "integrointipalavereissa" kuukausittain
  - Organisaation muuttuminen esitetty diplomityössä (esimerkit kuvattu) → esitetään asuntokirjaston ohjausryhmälle
  - Mittarit asuntokirjastohankkeille esitetty diplomityössä → esitetään asuntokirjaston ohjausryhmälle

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3

WORKSHOP 2 XX.12.2020

- **Osallistujat**
  - Juha Eloranta (Diplomityöntekijä)
  - Mikko Anttila (Hankintajohtaja)
  - Rami Sariola (hankintapäällikkö)
- **Aihe**
  - Asuntokirjaston maturiteettimallin jalkautus ja integrointi hankinnan näkökulmasta
- **Huomiot**
- **Jatkotoimenpiteet**

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4

WORKSHOP 3 XX.12.2020

- **Osallistujat**
  - Juha Eloranta (diplomityöntekijä)
  - Topi Laine (Johtaja asuntorakentaminen)
  - Juha Lanne (Johtaja hankekehitys)
  - Santtu Hokkanen (Suunnittelupäällikkö)
  - Tero Vanhanen (Ilmiörakentaja)
- **Aihe**
  - Asuntokirjaston maturiteettimallin jalkautus ja ohjausryhmän viimeiset kommentit
- **Huomiot**
- **Jatkotoimenpiteet**

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5

WORKSHOP 4 XX.12.2020

- **Osallistujat**
  - Juha Eloranta (diplomityöntekijä)
  - Topi Laine (Johtaja asuntorakentaminen)
  - Juha Lanne (Johtaja hankekehitys)
  - Santtu Hokkanen (Suunnittelupäällikkö)
  - Tero Vanhanen (Ilmiörakentaja)
- **Aihe**
  - Asuntokirjaston strategiamallin esittely ja ohjausryhmän viimeiset kommentit
- **Huomiot**
- **Jatkotoimenpiteet**

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6

KUUKAUSITTAINEN LÄPIKÄYNTI OHJAUSRYHMÄSSÄ

- Missä ollaan maturiteetti malliin nähden?
- Mikä osa-alue on jäänyt kehityksestä?
- Miten se saadaan samalle tasolle?
- Mitkä ovat stepit, että päästään seuraavalle levelille?

Nämä viedään roadmap:iin

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7

H1 JA H2 LÄPIKÄYNTI OHJAUSRYHMÄSSÄ

- Missä ollaan strategiaan nähden?
- Mikä osa-alue on jäänyt kehityksestä?
- Mitkä ovat stepit, että päästään tavoitteeseen?

Nämä viedään roadmap:iin

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