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Modeling the selection process of solution combinations in the design phase of residential construction

Master’s thesis

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Abstract

To increase the productivity and predictability of construction projects, construction companies should invest in the design phase of construction, where the impacts of building solutions and their combinations are extensively evaluated basing the selections on the most value generating combinations. Prefabrication and modular building solutions have a great potential in value generation, that has though been unable to be shown with the current direct cost-based selection methods.

The aim of this research was to model the current selection process of building solutions and develop a method to identify the dependencies and constraints as well as the direct and indirect costs of building solutions already in the design phase. In addition, the current tools developed to support this process were mapped out and a new tool was developed to support impact analysis of building solutions. With the produced process, the focus in the selection process of building solutions was attempted to be shifted from relying on empirical tacit knowledge into an open and justified selection process as well as in enhancing learning from project to project.

The thesis was carried out as a design science research that was divided into two phases. In the first phase a preliminary process for the needs of the residential construction unit of the case company was formulated based on a literature review and semi-structured interviews. In the second phase the process was tested in practice, and a final process was formulated based on the development needs arisen. On the grounds of testing, the organization’s ability to perform front-end weighted impact analysis was identified, as well as the functionality and development needs of the developed tool.

In this research was found that there is no structured impact analysis in the industry, that has led to basing the selections of building solutions on empirical knowledge and assumptions. The importance of the early stages of design are not fully understood at the moment, which has for its part resulted in surprises and poor productivity in projects. Impact analysis was found to be extremely difficult because of the variation in alternatives and projects that could for its part explain its absence in the current processes. To further modular building solutions and increase the degree of prefabrication in projects, the construction companies should invest in front end weighted design, where the impacts of building solutions and their combinations are identified and considered already in the design phase. The selection process of building solutions can be developed by standardizing the selection process where an extensive impact analysis and documentation as well as value-based selection are included.

Keywords residential construction, building solution, solution combination, design management, modular construction, indirect cost, impact analysis, CBA
Rakennushankkeiden tuottavuuden ja ennustettavuuden parantamiseksi tulisi rakennusliikkeiden panostaa suunnitteluvaiheeseen, missä rakennerratkaisujen ja niiden kombinaatioiden vaikutukset arvioidaan laajamittaisesti perustuen valinnan eniten arvoa tuottaviin kombinaatioihin. Esivalmistelussa ja modulaarissilla rakennerratkaisuilla on suuri potentiaali arvon tuotossa, jota ei kuitenkaan pystyet tunnistamaan nykyisellä suoriin kustannuksiin perustuvalla valintamenetteleyllä.

Tutkimuksen tavoitteena oli mallintaa nykyinen rakennerratkaisujen kombinaatioiden valintaprosessi sekä kehittää manetelmiä, jolla rakennerratkaisun riippuvuudet ja sidonnaisuudet sekä suorat ja välilliset kustannukset voidaan tunnistaa suunnitteluvaiheessa. Lisäksi tutkiin, mitä työkaluja oli jo kehitetty prosessin tueksi ja kehitettiin uusi työkalu rakennerratkaisun vaikutusten analysointiin. Luodulla mallilla pyrittiin siirtämään rakennerratkaisujen valinnan päätapoa kokemusperäiseksi hiljaisesta tiedosta aivoimen ja perusteltuun valintaprosessiin, sekä tehostaa projektien välistä oppimista.

Diplomityö toteutettiin suunnittelututkimuksena, joka oli jaettu kahteen vaiheeseen. Ensimmäisessä vaiheessa kirjallisuuskatsauksen ja teemahaastatteluiden pohjalta muotoiltiin alustava prosessi kohteyrityksen asuntorakentamisen yksikön tarpeisiin. Toisessa vaiheessa prosessia testattiin käytännössä ja esiin nousseiden kehityshdotusten pohjalta muotoiltiin lopullinen prosessi. Testauksen perusteella tunnistettiin organisaation kyky etupainotteeseen vaikutusten analysointiin ja työkalun toimivuus käytännössä, sekä siihen liittyvät jatkokehtitystarpeet.


Avainsanat: asuntorakentaminen, rakennerratkaisu, ratkaisukombinaatio, suunnittelun ohjaus, modulaarinen rakentaminen, epäsuora kustannus, vaikutusten analysointi, CBA
Acknowledgements

The topic of modeling the selection process of building solutions has not been studied before in the extent done in this research nor has the problems related to the absence of the process been identified in the industry. I want to acknowledge the professionals at Fira for identifying the need for this research and for giving me the opportunity to write this thesis. The truly interesting subject turned out to be extremely challenging that in turn provided great focus and energy that led to many new findings.

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1 Introduction

1.1 Background

The construction industry has been suffering from low productivity for several years. Construction projects are often considered to be non-recurring, unique projects that have little opportunities in repetition and standardization. (Bertelsen 2005) It has been recognized that the construction process has a lot of waste especially compared to the manufacturing industry, where processes are well managed and standardized. Even though construction differs from manufacturing in many ways, Aapaoja and Haapasalo (2014) argue that there are many processes in the construction project that could be developed in order to reduce waste. Also Barbosa et al. (2017) identify several reasons for the productivity issues of the construction sector, that include the heavy regulation and high dependency on the public sector, inconsistencies in the agreements, unexperienced owners and buyers that are struggling to tackle the opaque market as well as construction being fragmented and risky. As a result, project execution as well as project management perform poorly, the design process is insufficient and there is too little investment made in developing competences, research & development (R&D) and innovation. (Barbosa et al. 2017) Bertelsen (2005) suggests that misunderstanding construction could be a reason for the productivity issues as unforeseen situations, cost and schedule overruns, accidents and mistakes tend to be more of a rule rather than exception in the field.

Besides waste, the construction industry also suffers from quality problems and lack of cooperation and communication. In the recent years, several Lean practices such as the Last Planner System, Big Room methods and takt-time planning that are familiar from the manufacturing industry have been implemented to the construction industry especially in the design and production phases. Aapaoja and Haapasalo (2002) identifies the shattered supply chain of the construction industry as the main reason for the lacking cooperation that in turn is the root cause of hindering standardization in the industry. The industry has great potential for additional value added but it has not been successfully realized even though the challenges are well known, and discussion has been going on for a long time. (Barbosa et al. 2017) A great deal of the research made in the recent years has dealt with intensifying the production phase of a construction process. On top of the clear areas of improvement there, several other processes occurring before the actual construction such as design management has also been identified (Fosse & Ballard 2016). Also Aapaoja and Haapasalo (2014) came to the conclusion that the construction industry should focus on developing standardized processes where the main focus is on the front-end-weighted design that supports the usage of prefabricated building solutions.

As a standardized process is often lacking, utilizing knowledge and learning from past projects is still problematic (Dave & Koskela 2009). This leads to reactive problem solving and reinventing the solutions, when information from the past projects is lost and standardization does not occur. The process of selection of building solutions is often lacking, and as a result, it remains unclear what the decisions are based on. Also documenting the process is often insufficient, and decisions are made in informal settings, such as coffee table conversations that leave no records, leading to no learning and database for the next project. (Blismas et al. 2006) As a result, decisions are often based on experience and opinions, rather than actual data. Standardization of the design process, utilization of solution libraries and better knowledge on the effects of building solution choices would guarantee better constructability and success in the projects. This was also concluded by Barbosa et al. (2017) in their research, where the findings included that
reinventing the design process could improve the productivity of the whole construction project by up to ten percent, without changing any other functions related to the project.

New production methods are also setting more and more demands for the design phase of a construction project. Modular building has been introduced to the construction industry as an effort to stabilize the production environment by moving the production into factories and speeding up the construction phase as in stead of building everything on site, construction could be only assembling bigger pre-fabricated blocks. Prefabrication is said to be one of the most promising ways to develop the productivity and value creation as well as bring Lean practices into practice. (Aapaoja & Haapasalo 2002) Modular building requires more extensive planning but the quality is improved, and waste is diminished and thus the overall productivity is increased. These gains of modularity have been though hard to realize, as the indirect cost gains are hard to estimate, and the more extensive requirements of design and design management are evident. Thus, the adaptation of modular solutions has been slow, despite the suggested benefits by many researches. (Blismas et al. 2006)

1.2 Motivation and selection of subject

The lacking process in the selection of building solutions is typical in the whole construction industry. The absence of a process and selection based on direct costs have made adaptation and justification of some building solutions difficult. This has been especially evident with modular building solutions, for which the current selection is often based on assumptions on savings and profitability. Because no methods to analyze the impacts of the solutions in advance exist, these assumptions have often been overridden by the direct costs in the selection process.

These issues are also evident in the case company of the research Fira Group Oy (later Fira), and the choice of topic arises from the needs of better understanding the selection process of building solutions as well as their effects on other solutions and costs in residential construction. Fira is a Finnish construction company that focuses on developing the construction industry towards a more service-oriented direction. Fira does project development, residential construction, commercial construction, modernization and pipe renovations. In 2017, the net sales of Fira grew by 29 percent reaching 217.4 million euros, from which 68.2 million euros came from the residential construction unit.

Fira has started its business in the construction of parking halls and facility construction and is relatively new in residential construction. Because of this, some of the problems faced in the unit are based on the lack of experience and reference. Also, the projects done have been significantly different from one another and included special solutions that have been implemented for the first time. Fira focuses on development and innovation and is involved in many development projects such as Visio and Diction projects. In year 2016, Fira was the main contractor in the residential construction project. Viuhka housing cooperative, that won the concrete structure of the year award (Vuoden betonirakenteen). The building had a lot of prefabricated building parts such as concrete element balconies that are laid as a single piece. This type of cube balcony, called Noppaparveke, is developed by Fira. Fira has also developed its own bathroom elements, called Modules that incorporate the plumbing and sewage systems as well as finishing and fixtures readily installed. Modules is used in Fira’s own residential construction projects as well as sold to other construction companies. In addition, Fira has cooperated with Lujabetoni in the development of a new baffle plate solution, called Luja-Superlaatta. This pre-stressed concrete plate structure allows long spans and the tubing for electricity installations as
well as floor heating (either water circulation or electrical) is readily installed in the factory. All of these solutions are meant to shorten the building time and ease the construction work done on site by moving fabrication into factories.

The current main development targets of the residential construction unit of Fira are implementation of takt-time on the internal building works phase and to clarify and make new process descriptions for the design phase. A need for standardization of building solutions as well as processes has been identified. Lean practices such as Big Room and Last Planner System (LPS) have been implemented mainly in the design and construction phases respectively but a productivity issue still remains in the unit. Fira has made several efforts in order to correct the productivity issues but the actions have focused on reactive corrective measures rather than proactive measures. Because it takes several years to learn through the reactive measures and the feedback from the production phase, a need to act proactively already in the design phase has emerged.

The design management process in Fira has been investigated earlier in the form of Master of Science Theses by Lehtovaara (2018), Hannonen (2017), Juntunen (2015), Aho (2014) and Karhu (2013). Lehtovaara focused on improving the learning of the design management by developing a learning model by which feedback about building solutions could be collected, analyzed and stored. The model focused on finding the root causes of the problems faced in the construction phase and storing the information for the use of future projects. (Lehtovaara 2017) Hannonen (2017) investigated the effects of design changes on project costs and weather they could be controlled by design management. Choosing By Advantages (CBA) and a more detailed process description were suggested as improvements in the concept design phase. In addition, a better flow of information and utilization of change orders in proactively removing barriers in future projects were identified as areas of improvement at Fira. (Hannonen 2017) Juntunen (2015) described the Big Room process as a part of design management of the detailed design phase in Fira and investigated if Big Room methods could be used to prevent problems in design management. A detailed process description and instructions were obtained but Big Room methods were obtained to have little to no effect in preventing problems because the success of design management and the whole project depends on various things that may not be influenced by Big Room activities. (Juntunen 2015) Aho (2014) developed a project handbook for the design-build project delivery method. The findings included issues due to the lack of process descriptions that lead to building solutions not being analyzed thoroughly, insufficient control of designers and schedule issues. Process improvements and specified design meetings were suggested as improvements in order to increase productivity of the design process. (Aho 2014) Karhu (2013) suggested the reverse SUKE design and procurement process and Building Information Modeling (BIM) principles in order to improve the design process. This model is no longer in use in Fira (Fira 2019).

1.3 Research objective and research questions

The main objective of this study is to develop a process by which the dependencies and constraints as well as the direct and indirect costs of a specific building solution can be identified in the design phase of residential construction. The existing tools to support this process are mapped out and a new tool is developed if the existing tools are found insufficient. Therefore, the aim is to firstly describe the existing situation and tools, secondly to model the selection process and thirdly, if needed, to develop a new tool to support the process. The study also aims to identify and describe the necessary viewpoints and considerations in making an informative decision of a building solution. The process solves the productivity issue of the case company, where the current selection of solutions
has led to unplanned increased costs and undesirable structure combinations. Although the process is developed for the needs of the residential construction unit, it might be applicable also to other units in the company, such as the facility or repair construction units.

The research objective is addressed with the following research questions (RQs):

RQ1: How could the dependencies and constraints as well as the direct and indirect costs of a building solution be identified and documented?

RQ2: What are the viewpoints that need to be considered during the selection of a building solution? Which project parties should be involved?

RQ3: What aspects should decision-making on building solutions be based on?

The first RQ strives to address the methods for identification of the dependencies and constraints as well as the direct and indirect costs of a specific building solution under review. This includes identification of the different forms of dependencies and constraints between building solutions and the sources for costs. The second RQ aims in mapping out the different viewpoints that need to be regarded when considering the selection of a specific building solution. All of these viewpoints may not necessarily result in decisive factors, but still require consideration in order to the solution to succeed. As there are generally several different project parties involved in residential construction projects, the necessary parties related to these considerations are strived to be found. The third RQ focuses on identification of the decisive aspects on the selection of building solutions. Therefore, RQ2 and RQ3 can be seen to complement each other, as both the viewpoints requiring consideration and the finally decisive factors are addressed and also separated from one another.

In this research, the term building solution is used for a structural part of the construction that serves a specific function and has an effect on the function of the affiliated structures, such as slabs, balconies and roof structures. The building solutions can be ranging from simple beams to complex, prefabricated modules, such as a bathroom module. A solution combination consists of the building solution under review and the building solutions affiliated to it. For example, a sandwich wall element is a building solution that makes a solution combination with the slabs, windows, doors and foundations, that are all also building solutions. In addition, the wall element might be coated with paint but because this does not change the function of the element, the paint coat is not considered as a building solution on its own. The term design solution is considered to be partly overlapping with the term building solution. In this research, design solutions are considered to include the building solutions, as well as aspects like the size and shape of the building, number of stories and the floor plans. A building solution is therefore a design solution that concerns a definite part of the building.

This research focuses on the selection process of building solutions in project planning and options appraisals phases which are located between the needs assessment and concept design in the construction design process. The research is limited to investigation on modular solutions, as the selection process of them requires extra attention in the case company. Modular building solutions generally hold more dependencies and constraints needed to be solved already in the design phase, as they are often prefabricated elements where changes are not possible later in the process. Therefore, the selection of them is
more demanding, requiring special consideration of impacts on the affiliated building solutions. Although the developed process could be utilized also in the selection of non-modular building solutions, this is not evidenced in the research.

1.4 Research approach and structure of work
1.4.1 Research methodology and approach

In this research, Design Science Research (DSR) methodology is chosen because it focuses on the development of actual artifacts, such as products, processes, models or systems. (Kanjjanabootra 2016) DSR, also called constructive research has often been used to solve practical problems while also providing theoretical contribution (Rocha et al. 2012). The research methodology often involves close collaboration between the practitioners and the researcher and is sometimes linked with design thinking. In engineering and construction fields, DSR has been used because it enables a more practical research style that develop the practices and processes that the practitioners actually need. (Kanjjanabootra 2016) Because one of the main objectives of this research is to improve the existing practices in such a way that continuous improvement can take place, this type of collaborative style that also involves the actual users of the end results is essential (Anderson & Shattuck 2012).

Instead of only testing theories and quantitative analysis, DSR methods are often focused on problem solving by the means of development and evaluation of the artifact. Evaluation is based on the usability and value of the result and whether it solves the identified problem. (March & Smith 1995) In this research, the artifact is the selection process of building solutions. A major characteristic of DSR is its stepwise progressing nature and development in cycles that include development of both practical and theoretical frameworks (Rocha et al. 2012, Vaishnavi et al. 2004/17). Vaishnavi et al. (2004/17) describes the DSR process to be composed of five steps that are described in Figure 1 below.

![Image of DSR process diagram]

* 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)
The process starts with an awareness of a research problem, that can originate from multiple sources, such as developments in the industry or within a reference discipline. This step produces a proposal for research, that is followed by the suggestion. The suggestion phase could be seen as an integral part of the problem awareness phase, as any formal proposal should also include a tentative design on how to begin to solve the problem. If after considerable effort on a problem there is no sentiment on a tentative design, the proposal should be set aside, and the process terminated. Suggestion phase is a creative step where new functionalities are envisioned based on existing or new and existing elements. Suggestions may be based on existing knowledge or theory but include knowledge gaps or be in some other way inadequate for the problem, and therefore require innovative formulation so that the problem can be solved. The output of this step is the tentative process, that is believed to solve the identified problem. This tentative process is implemented and further developed in the development phase. The form of implementation depends of course on the artifact and can be simple, with the focus on the design and not the construction of the artifact. This step produces a completed artifact that is evaluated in the next step. The development phase can include several implementations, that are evaluated according to a specification. Evaluation is based on the functionality of the artifact and any deviations from expectations, both qualitative and quantitative are noted and tentatively explained. In the evaluation phase, knowledge from the process and the results are gathered and fed back to the process, so that new problems are identified. The development, evaluation and suggestion steps are iterated during the research effort. The process is finalized with the conclusion phase, that could be the end of a cycle or the end of a specific research effort. The knowledge contributed and the research itself is carefully reported and documented, providing an output of research results. (Vaishnavi & Kuechler 2004/17)

The research has also many properties of a case study research. As the research is limited to the development of a certain process in a specific company, producing case specific information can be seen to be generated. On the other hand, a case study research should strive for understanding the phenomena related to the case on a more general level. (Saarela-Kinnunen & Eskola 2001) This research is conducted for the means of the residential construction unit of Fira, that could be seen to represent a fairly typical middle-sized contractor in residential construction in Finland. Therefore, the results of this research can be seen to be adaptable also in a broader context.

In order to maximize credibility and adaptability of the research, a mixed methods research style is selected. A different research method is chosen in different stages of the research process, depending on the needs and characteristics of the process stages. The research is mostly qualitative in nature, as solving the research questions requires an extensive understanding of the construction design process in the case organization. The DSR method has also been criticized because of its non-repeatability that originates from the creative process. This is addressed by detailed descriptions of the steps in the process, as well as the different research methods.

1.4.2 Structure of work

Following the DSR process by Vaishnavi & Kuechler (2004/17), this research is divided into five main parts illustrated in Figure 2. These parts and their objectives and outputs are described in detail below.
Figure 2 Structure of work.

Awareness of the problem

The problem arises from the needs of the case company. This phase includes getting familiar with the specific problems that the organization is facing regarding the particular process under review. Research motivation and selection of subject is formulated in chapter 1.2. based on the issues recognized from literature and experienced by the experts in the company. The specific research questions and objective are formulated by the researcher based on the problem and are presented in chapter 1.3.

Suggestion

The development of the solution suggestion starts with familiarizing with the existing process and literature. This is done by conducting a literature review that pursues to familiarize with the existing research on the subject as well as gain knowledge on the possible methods and processes already developed to solve the problem. The literature review is presented in chapters 2 and 3, where chapter 2 focuses on the overall construction design process and chapter 3 on the selection of building solutions. In chapter 4, the findings of the literature review are summarized. In addition, the current process in the case company is mapped out by participant observation by the researcher in design meetings and Big Rooms as well as by conducting semi-structured interviews. The interview process and findings are presented in chapter 5.

The main objective of the suggestion phase is to gain an understanding of the current process in the company and its challenges, the tools available to support the process both
in literature and inside the company and to fill the gaps in these tools so that the problem could be solved. The suggestion that fulfills the obtained gaps in existing practices and solves the identified problem is developed together with the professionals from the case company. A workshop type method is applied in the formulation of the process. The process is developed in a project that is already in the construction phase in a kind of backward nature. This means that issues regarding the dependencies and constraints of building solutions as well as unplanned costs that should have been taken into account in the design phase but have not, and that have become visible only once the construction phase has started are regarded in the developed process. In other words, learning from mistakes that are presently common in the projects are attempted to be turned into a process by which the project’s problems could be foreseen. Based on the findings, a tentative process is produced. The tentative process in presented in chapter 6.

**Development**

The obtained tentative process is implemented in a project without active participation of the researcher. Special attention is drawn to the nature of the process, so that it can be easily further developed without the researcher leading the development cycles. The aim of this phase is to put the process into practice as a standard part of the design process in the company, so that the research would not remain out of touch to the actual practices and on a theoretical level only. In this phase, the researcher acts mostly as an observer in order to be able to suggest development needs in the process and start the continuous cycles of implementation and development. The development phase is presented in chapter 7. The output of this phase is the ready process.

**Evaluation**

In chapter 8, the process is evaluated. The researcher evaluates the performance of the process and the degree of solving the problem. The further development needs are identified and presented and the procedures for continuous development of the process are described. In addition, the scientific contribution of the research as a whole is evaluated, and the limitations of the study discussed.

**Conclusion**

The end of the research marks the end of the development cycle of the process. In chapter 9, the conclusions of the research are presented and the possibilities for future research introduced.
2 Construction design process

Construction is a project-based industry, that is traditionally believed to produce unique products with temporary project organizations (Ballard & Howell 1998). The design process has been identified as one of the most important functions in the project, as the plans strongly dictate the success of the whole project (Mujumdar & Maheswari 2018).

The design process consists of different phases that are represented in Figure 3. The process starts with needs assessment, where the need for the building and spaces are defined, and the initial building solutions and their demands are selected. Based on these, the initial costs of the project are determined and the decision of weather or not to proceed with the project is made. (RT 10-11109 2016)

![Construction planning diagram](image)

Figure 3 Design process in construction projects.

Project planning is a thorough assessment on the fundamentals and requirements of the project as well as the needs in order to achieve them. In the project planning phase, the initial room program and properties and the implementation schedule are set. The goals concerning scope, quality, costs, timing and upkeep of the final construction are also defined in this phase. (Kankainen & Junnonen 2015) These should be well defined so that extra work caused by lacking information is minimized, and remain unchanged when moving further in the design, as this causes rework. (Koskela 2000) The building site is investigated, and an operational, technical and zoning report are conducted. Based on the room program and these reports, the target price of the project is set. (Kankainen & Junnonen 2015) The decisions made in this phase are crucial for the success of the project, as the site conditions, zoning regulations, building type and size as well as parking solutions and main material choices set over 50% of the project’s final costs. (Kuusela 2018) All future decisions must also be based on the decisions made in this phase and are restricted by them.

Koskela (2000) defines construction planning as a process where information that defines the demands and needs of a product is transformed into information about the product. The aim of construction planning is to produce best attainable quality with the available resources. (Kankainen & Junnonen 2015) Construction planning starts with options appraisals and moves to concept design and detailed design gradually increasing the level of detail. Each phase involves different project parties and requires decisions to be able to move on with the project. The project parties typically include the owner, the customer of the building project, the users, the developer, the designers, the constructors, different material and product suppliers and the authorities. Depending on the situation, the owner can be the same entity as the customer as well as the end user or even the developer. (Kankainen & Junnonen 2015) Also the project delivery method defines the roles of the project parties. The most common project delivery methods used in residential construction in Finland are different design-build (DB) methods, design-bid-build (DBB) and a divided contract method that include different types of construction management (CM)
The process is controlled by the design requirements that are, if contracting for customers, the requirements of the customer. (Koskela 2000) As the selected building solutions and design management only account for about 20-40% of the project’s total costs (Kuusela 2018), the focus should be on creating value, as these are the decisions and choices that are going to affect the functionality of the product and fulfillment of the customer’s requirements. (Aapaoja & Haapasalo 2002, Koskela 2000)

### 2.1 Characteristics of the design process

The design process is considered to be extremely demanding, since it is mainly a creative thinking process where designers have to create and explore alternatives that satisfy the client’s requirements and translate them into drawings and specifications. (Rosas 2013) The design process can be characterized as cyclic, evolutionary and iterative (Mujumdar & Maheswari 2018), consisting of three aspects that are:

- The creative process where different design options are created
- Design documentation, where the selected solutions are formulated into design documents
- Decision-making process, where the decisions regarding what to build and what to design further is made (Bolviken et al. 2010).

The design process involves continuous decision-making in order to be able to move on with the process, as many design tasks are dependent on each other and there is no use to start subsequent tasks if there is still uncertainty in the initial data of the previous task. Design is though not a process of sequential tasks, but many tasks have to be developed and decided simultaneously (Rosas 2013). The design process involves designers from many different disciplines such as architecture, electrical, HVAC and structural engineering, that all produce deliverables related to their own fields that together form the building solutions and the whole building. The relationship between the different design tasks can be typically divided into four types that are independent, semi-independent, dependent and interdependent (Figure 4) (Mujumdar & Maheswari 2018).

![Diagram of design dependencies](image)

Figure 4 Dependencies of design tasks. (Mujumdar & Maheswari 2018)

A typical design process involves all four types of information dependencies, from which interdependent tasks are the most challenging, as they require assumptions to be made. (Mujumdar & Maheswari 2018) Knotten et al. (2014) propose that the design process can be regarded to have a two-dimensional logic, consisting of a sequential logic and a reflective logic. The sequential logic consists of tasks from each design discipline that are dependent of each other in a serial form whereas the reflective logic includes tasks that are interdependent of more than one discipline, following more a reciprocal dependence (Figure 5). Especially in the beginning of the process the design tasks often follow the reflective logic, but as the design process moves forward, the tasks begin to follow more and
more the sequential logic. Therefore, the beginning of the design process can be seen as the most critical phase regarding design management. (Knotten et al. 2014)

![Diagram](image)

**Figure 5 Dependencies of design tasks.** (Adapted from Knotten et al. 2014)

The interdependent tasks that cause designing forced to be done with insufficient information lead to constant addition of level of detail that in turn is typical for the design process. (Koskela 2000) This also causes iteration, that is unavoidable in any design project. The iterations should be managed and planned appropriately, as unanticipated rework and redesign results in time and cost overruns. (Mujumdar & Maheswari 2018) Although iteration and rework are often caused by making decisions with insufficient information, making certain decisions is crucial in order to be able to proceed with the design process. (Koskela 2000, Raunama 2015) Decision-making can diminish the uncertainty related to the process, as it shifts the process more from a reflective logic towards a sequential logic. Decision-making should be goal-directed, assertive and timely (Raunama 2015). Decision-making is often based on cost comparisons so that it would not be based solely on experiences and opinions, although Raunama (2015) points out that expert views and experiences should be taken into account where necessary instead of only facts. (Raunama 2015, Viininen 2017)

Iteration and rework might also result from the fact that the dependencies of a building solution and its effects on the entirety as well as affiliated building parts might not have been sufficiently considered when selecting the solution (Koskela 2000, Raunama 2015). This type of sub-optimization might lead to unplanned increased costs, as the design team might end up in costly or difficult solutions if the decided building solution these depend on cannot be affected anymore. The dependencies of a building solution might be hard to foresee, because of the extremely complex nature of the product (the building), and the fact that each designer is an expert on their own field only and might not have the knowledge on the effects on other design fields. (Koskela 2000, Mujumdar & Maheswari 2018) This leads to sub-optimization of their own processes (Aapaaja 2014) when compromises between different design fields would have been needed (Koskela 2000). Selection of optimal building solution combinations requires collaboration to solve conflicts, keeping the shared goals, complete transparency, concurrent consideration of decisions and uniformity between the designers. (Koskela 2000)
Because the construction projects are often considered as one-time occurring, unique projects, also the design process is often seen as such. Considering the design process as unique leads to starting from zero every time as the knowledge from previous projects is considered to be unfit or not applicable to the situation. Also, because no two projects are truly identical, the current practices and tools of the design process have developed from the policies and procedures that are believed to have worked in the past or in other, similar situations (Koskela 2000). The ability to measure, understand and control the different variations is truly important for the success of the project and the process management. (Ballard et al. 2004) On the other hand, it is extremely hard to learn from the mistakes in the design process, as it is impossible to know to what extent a failure in the construction phase has resulted from a poor design solution. (Rosas 2013)

2.2 Quality of designs and the effect on project costs

The effect of design solutions on the economy of construction projects is significant in the sense that the cost dispersion between projects that have good design solutions and poor design solutions can be several dozens of percentage points (Vihinen 2017). A majority of the project’s costs are determined, but only a fraction accumulated in the design phase (Figure 6). (Kankainen & Junnonen 2015) This means that the designers and the design management largely determine the financial success of the project, even though in many cases the construction work is done by a different entity that hold the budget responsibility of the project. In some cases, such as in the DB delivery method, a single person can be responsible of the whole project first as a Design manager and then as the Construction manager. On the other hand, delivery methods such as DBB separate the design and building phases so that the designers have no information about the success of their design solutions and the responsibility of the correctness and necessary extent of the designs are on the owner. Because of this, same mistakes in the design process can be done repetitively without ever realizing it. These poor design solutions do not only affect the customer, but the whole project team. (Rosas 2013) Ideally in the construction phase, the resources can be used solely on execution, rather than further clarifications and uncertainty on what should be done. (Koskela 2000, Rosas 2013) Design errors usually come out as extra or rework, delays and changes. Hence defective design and correction of errors diminishes productivity and raises costs as well as delays the project (Riihilauma 2017).

![Figure 6 Determination of construction project costs. (Kankainen & Junnonen 2015, modified by Kira Kauppila)](image-url)
The success of construction planning is though hard to define consistently, as there are different project parties involved, each possibly having a different conception of the requirements of a good design. A good design can mean that there are no design errors or that the resources used in the design process are minor. A design might be flawless in the sense of design errors and be easy to execute but fail to meet the requirements of the customer. Therefore, considering only the success of the construction phase and the total project costs as a means of measuring the success of the project and the designs is not enough. (Whyte et al. 2003) Success in the project can be equally hard to define as it might consist of different things depending on the project party. The user of the building might value functional spaces where as the architect value the aesthetics of the construction. The project success is dependent on objective as well as subjective measures that can be, according to Chan & Chan’s (2004) research, measured with certain performance indicators. Often success of the project is considered from only three aspects that are cost, schedule and quality accuracy but also subjective matters such as the functionality of the building as well as the satisfaction of the project parties are becoming more and more important measures. Schedule accuracy also holds the concept of construction time. As there is always a need for greater effectiveness, there will be a need to finish projects faster. Also, the health and safety aspects, that is how well the prevention of accidents and injuries has been done, are becoming more and more visible as project success measures. The construction industry has focused on safety for a long time already, but as a project success measure it still does not reach the most important ones. Construction projects and the usage of the building have a massive effect on the environment and that is why some developers value the environmental performance of the building as a measure of project success. Value and profit are important success factors for the customer, as the end result of the project determines the value of it and by that the profit gained. (Chan & Chan 2004). These success factors are listed in Figure 7 below.

![Figure 7 Measures of project success. (Adapted from Chan & Chan 2004)](image)
Generally, the constructor expects that the design work is done according to the schedule, that the produced designs are nearly flawless, cost efficient, well matched so that there are no clashes and implementable. (Raunama 2015) According to a study made by Junnonen & Kärnä (2015) based on the material collected by The Construction Quality Association (Rakentamisen Laatu RALA ry) in Finland, there seems to be major problems in the above-mentioned areas. In this study, the feedback from different project parties in nearly two thousand construction projects in Finland were analyzed. The feedback from the main contractors to the designers is presented in Figure 8 where 1 describes the claim extremely poorly and 5 extremely well. Most of the problems, according to the developers and contractors, were thought to be in the flawlessness, compatibility and consistency of the plans. Also design management was thought to be insufficient, which was in turn believed to be a root cause for the lacking design content. The designers wished that the main contractors would adduce their expertise more eagerly and introduce alternative building solutions for the designers. On the other hand, the collaboration between the designers and the rest of the project parties was believed to be good, as well as the competeny of the designers. (Junnonen & Kärnä 2015)

Figure 8 Feedback from main contractors to designers (N=334). (Adapted from Junnonen & Kärnä 2015)
2.3 Design management

Design management aims in controlling the design process so that it reaches the appointed goals and produces functionally, economically, aesthetically, technically and environmentally acceptable plans. (RT 10-11107 2012) Design management is also cost management, as the appointed goals are attempted to be achieved with minimal cost. This includes setting a realistic target price in the project planning phase and managing the selection of building solutions in the construction design phase so that this target is met. (Lindholm 2009) Because construction is heavily regulated, all the building solutions and costs cannot be affected with design management, as zoning regulations and other decrees set some restrictions to the available alternatives. (Pitkänen 2009)

Design management is a combination of process control and design leadership. The Design manager has to make sure that the right things are expedited at the right time, so that changes in the made plans and waste is minimized. Active leadership is required in order to produce consistent plans that take into consideration the needs and goals defined throughout the process. To achieve this, collaboration and communication between the whole design team is inevitable. (Rosas 2013) Scarcity of these are the root causes of most of the challenges faced in design management. (Pikas et al 2016) Design work is also often done with defective information from the ones actually completing the work (ICG Guideline 2015), which means that their preferences, skills and expertise knowledge on the matter might be neglected without active design management practices.

The lack of a working process has been identified as one of the major challenges of design management (Koskela 2000, Daniel et al. 2017). Construction projects today are considered to be somewhere between traditional, fully unique projects and complete manufacturing. Therefore, the practices of the manufacturing industry cannot be applied to the construction industry as they are. (Höök 2008) Many researches though suggest that considering the design and design management more like a standardized process and focusing on the flow of it, the productivity of the whole construction project would be improved. (Höök 2008, Aapaoja & Haapasalo 2014, Daniel et al. 2017) Aapaoja & Haapasalo (2014) point out that standardization in the construction industry should not be only thought as standardization of a product or system, but rather a systematic way of performing things that could be applied to different phases from design to construction.

The use of structural libraries and parametric design tools have been introduced as an effort to make the designs and processes more standardized and to utilize existing information in the design phase. Construction companies often gather a structural library, that holds information on the typically used structures and their prices based on past projects and empirical data. These libraries are often cost oriented and used as a tool in cost estimating. The main idea is that the cost knowledge is kept agile and up to date, so that it can be used easily. (Talo 90-ryhmä, 1994) Because of the solely cost oriented nature, decisions on the choices of building solutions cannot be explicitly based on the structural libraries, and therefore are not a comprehensive tool for the Design managers. In addition to company’s own libraries, common structural libraries exist and are often utilized as a base for digital modeling tools.

The current building design is often based on the use of BIM models. BIM models are an effective tool to among other things visualize different design options, perform collision detection and calculate different key figures of the project. (RT 10-11066 2012) BIM is an effective tool for Design managers, as it simplifies the process by enhancing information exchange, helps to detect faults and collisions that decreases the need for rework.
and shortens the design period. (Eastman et al. 2011) Although BIM is a good tool for visualization, modeling different alternatives just to find out their effects on the whole can become overwhelming, because of the infinitely existing alternatives. Utilizing the model or preliminary plans, Key Performance Indicators (KPI’s) are often calculated to ensure for example efficient use of spaces and minimization of exterior walls. In general, KPI’s aim at selecting the most cost-efficient structural solutions and layout options. (Kuusela 2018) As for the structural libraries, also the KPI’s require data from past projects or commonly used guidelines as a reference in order to serve effectively (Jokiniemi 1993). Although both of these tools can be used in managing the design, they do not account for the wide consideration of aspects and impacts that the selected solutions might bring. The designs might provide an effective layout and no collisions between the building systems but fail to take into account an extra need for supervision of work or for instance guarantee issues.

As an effort to take the broadest range of aspects into consideration when making decisions, Multi Criteria Decision Making methods (MCDM) have been adopted. MCDM is a general term for several different decision-making methods that all aim in helping to choose the best design alternative considering multiple factors. (Cortes et al. 2017, Arroyo et al. 2018) Analytical Hierarchy Process (AHP) is a widely used MCDM method that is based on assessing the decision criteria with respect to their relative importance by conducting pairwise comparisons between the alternatives. (Darko et al. 2018) Also other types of methods based on hierarchies, such as Decision Trees (Yu et al. 2010), Argument Trees (Cooke et al. 2008) and Value Trees (Emmott et al. 2005) have been developed. MCDM methods are further discussed in chapter 3.1.

### 2.4 Lean design management

Lean design is a term used for the application of Lean principles and methods in the design process (Hamzeh et al 2009). The basic lean principles are dealing with maximization of value, which is achieved by understanding the customer and the process, identification of waste and removal of non-value adding activities. (Rahman et al. 2012) The value creation of the design process can be argued to derive from variation, as the process seeks to find the optimal combination of building solutions which maximizes the value for all the stakeholders. This in turn is contradictory with Lean principles, that state variation in the process as waste that has to be eliminated. (Bølviken et al. 2010) As futile work and proceeding of the wrong things is typical for the traditional design process, adaptation of Lean methods in order to advance the right things at the right time and thus eliminate waste is crucial for the development of the design process. (Raunana 2015) Therefore, finding the right balance between exploring different variations and making decisions to be able to move on is fundamental. Past research in Lean Design Management (LDM) has focused mainly in flow management and waste reduction, disregarding value managing and enhancing aspects (Jørgensen 2006). Solutions to the challenges of the design process, especially issues relating to communication and collaboration have been attempted to solve by the means of LDM in the past years. In literature, the different social processes, design methods and tools or technologies have been mainly explored as means for taking lean principles into practice. (Uusitalo et al. 2017)

Last Planner System (LPS) is a method that has been researched quite a lot in the past years and applying it already in the design phase has proven to benefit the project (Fosse & Ballard 2016). LPS is above all a process control method, that focuses on the timely task execution and constraint elimination (Fosse & Ballard 2016, Hamzeh et al. 2009, Bertelsen 2005). Collaborative Planning in Design (CPD) is a method that builds on the
LPS method but focuses more on the design production and decision-making processes rather than on the design creation process. The method proposes that these three processes should be managed differently with the focus on collaborative design and dialog. (Bølviken et al. 2010)

Big Room has for many years been used as a means to improve the collaboration between the stakeholders in a project in the production phase as well as in the design phase. The purpose of Big Room is to gather all the different project stakeholders in a joint space where the critical problems can be addressed and eliminated jointly. The potential benefits of Big Room include improved collaboration and sharing of information, better project results due to early stakeholder integration and increased trust. (Majava et al. 2018) Concurrent engineering (CE) is a method of simultaneous designing and development of products, that aims in decreasing the development time and thus leading to improved productivity and reduced costs and is more familiar in the manufacturing industry (Ballard & Koskela 1998). Integrated Concurrent Engineering (ICE) in turn is an intensive collaboration method that produces rapid designs by gathering experts that solve interdependent design issues in consistent social processes and with advanced modeling and visualization tools. (Kunz & Fisher 2012, Avnet & Weigel 2009) These methods are mainly dealing with the overall design process management, focusing on the social process aspects.

Target value design (TVD) is a design method that aims in producing designs that create the greatest value for the customer and user. Early involvement of the customer and keeping the budget as a design criterion are characteristics of this method. (Merikallio 2015) Set-based Concurrent Engineering (SBCE) refers to a design approach where sets of possible solutions are generated and gradually narrowed down as the information increases, leading finally to the best design solution. (Ammar et al. 2017) Choosing by Advantages (CBA) is a type of MCDM design method that focuses on the selection of design alternatives based on their advantages.

Design Structure Matrix (DSM) is a tool for identification and allocation of the constraints between the different design tasks as well as finding the optimal execution order of the tasks based on the constraints. The information is gathered in a matrix form indicating the dependencies between the different design tasks. (Herva 2015) A3 Report is a tool that can be used either in problem solving or development. It is a standardized form of documenting a specific problem and its solving process as well as the follow-up procedures. (Sobek & Jimmerson 2006)

In the context of LDM, Virtual Design and Construction (VDC) is often mentioned as a more advanced technology than Building Information Modeling (BIM). VDC is the parametric modeling of the whole building and its technical systems that supports not only analysis and coordination of different building systems but also different analysis and project planning needs, such as prediction of the project schedule and cost. (Kunz & Fischer 2012)

The design tools and methods are often complementing and supporting each other and hence several methods are often needed in the context of the whole design process. There are also many other methods and tools than those mentioned here, but these are the most typically mentioned in literature. The different tools and methods are summarized in Figure 9 below.
This research focuses on the selection of building solutions, that is a part of the decision-making process in the construction design process. The actual selection process of building solutions and the identified two methods CBA and AHP, are further examined in the next chapter.
3 Selection of building solutions

Construction design is a decision-making process (Haymaker et al. 2018), where designers from different design fields transform the design requirements and restrictions into drawings and specifications. (Rosas 2013) There are different decision-making approaches, but generally the process involves a problem formulation as well as generation and exploration of alternatives before reaching a decision. Decision-making is often done based on previous knowledge and assumptions, since the usual budgets and deadlines of the project do not promote extensive evaluations of different alternatives. Often this leads to decisions where value is not maximized. (Haymaker et al. 2018) In order to make informative decisions, the design literature suggests exploring as many alternatives as possible from the viewpoints of experiential, ecological and economic factors within the project’s time and budget constraints.

Selection of building solutions starts already in the project planning phase, and the plans are constantly made more precise building on the previous decisions. (Rosas 2013, Keskela 2000) Because of this, already when making the first decisions, their impacts on the entirety should be clear, so that future decisions are not constrained in a way that will lead to non-optimal solution combinations. Because of this, the first impact analyses should be as extensive as possible, so that the far-reaching effects of the choices could be identified. An attempt to account for this issue is Set-based Design (SBD) practice, that keeps the design options and requirements flexible for as long as possible. Instead of choosing an option and progressing design work based on that option, several different options are explored simultaneously, making choices between the options only at the last possible moment. Therefore, commitment in solutions is made only after validating assumptions, and thus more informative choices can be made. (Singer et al. 2009) The practice is thought identified to have problems, as the efficiency of the design process may suffer if the design space is divided into too many concepts that are all furthered at the same time or on the other hand if the concepts are too broadly defined so that it is not possible to eliminate any of them and the process is not moving forward.

Besides the decision-making, the current selection methods include also other limitations. The used methods are often based on only evaluation of the direct costs of a solution, such as the immediate material, labor and transportation costs. Because of this, unplanned cost overruns in the construction phase are prone to occur, as indirect costs such as crane use, site facilities and storage as well as management costs are not evaluated in the selection and estimations. Gaining knowledge of these costs is also extremely difficult, as they are often not accounted as relating to the costs of the building solution, but under some other cost category, such as operating and joint costs. (Blismas et al. 2006) Therefore, solutions with economical direct costs but expensive indirect costs might be selected repeatedly disregarding that a solution with expensive direct costs, but economical indirect costs might actually be a more cost-efficient alternative.

Sorri (2013) identifies schedule effects as the second most important factor affecting the choices of building solutions after cost factors. The constructor might decide to adopt more prefabricated solutions, if the overall project schedule is tight and the onsite activities have to be completed rapidly. (Sorri 2013) In addition to direct cost comparisons and schedule restrictions, the selection of building solutions is often based on opinions and past experiences. (Blismas et al. 2006) Experienced designers and project managers rely on solutions that have been used before, conducting comparisons only if the situation is unique such as an extremely tight project schedule, or solutions that they are not familiar
with are desired by the customer or other stakeholder. Designers might also rely on the image they have of the costs of a certain solution, without making actual comparisons. (Haymaker et al. 2018)

As there are different project parties involved and their goals and constraints to consider, the decision-making on different design and building solutions can be demanding. Also, often a demand must be considered together with several different subsystems that are all designed by experts from different fields. Hence, the optimal design solution consists of countless compromises that must be made wisely so that the main needs of the customer are fulfilled. (Koskela 2000) The different project parties identified in chapter 2 are either stakeholders affected by the decisions and defining objectives such as the customer, gatekeepers applying constraints such as authorities, designers generating and analyzing alternatives or decision-makers. The goals, by the stakeholders, and constraints, by the gatekeepers, of the problem are identified and formulated. After this, alternatives solving the problem are generated by the designers and their impacts are analyzed. The decision maker makes an assessment on the value of the solution based on the preferences and impact analyses before making the decision. The selection process is represented in Figure 10. Although the process is described to have a start and end point, the processes are iterative. (Haymaker et al. 2018)

![Diagram showing the selection process of building solutions.](Adapted from Haymaker et al. 2018)

There are several tools and methods developed to support this four-staged process. These tools and methods are presented and evaluated in chapter 3.1.
3.1 Current decision-making methods

The more complex the product and options are, the more difficult is the decision-making process, as identifying the indirect effects becomes increasingly challenging. Several different methods and tools have been developed to support the decision-making process, that aim in taking multiple criteria in consideration to maximize value. Zavadskas et al. (2018) reviewed the current evaluation and selection processes in civil engineering and found out that several different MCDM methods have been developed, that their application has been growing particularly in the last three years and that they hold a great potential for sustainable decision-making in the field. These MCDM methods have several different approaches, but usually they are meant to compare a prefabricated building solution to an onsite produced corresponding solution (Pan et al. 2012, Pasquire et al. 2005, Blismas et al. 2006, Elnaas 2014). Research in the last years has also aimed in justifying sustainable attributes in building solutions that would otherwise be neglected with an approach focusing only on the direct costs (Kamali & Hewage 2017, Zolfani et al. 2018, Arroyo et al. 2014b). Although the methods aim in taking indirect aspects in consideration as much as possible, there are different attributes considered in the different methods. The aspects considered in some of the MCDM method researches made in the past years are summarized in appendix 1. The three most covered aspects in the reviewed researchers are material costs, life cycle performance and health and safety risks. In general, the aspects are often seen to cluster under three themes that are environmental, social and economic sustainability. (Kamali & Hewage 2017, Zolfani et al. 2018)

Even though MCDM methods have been widely developed and studied, it seems that no method in particular has gained a solid foothold in the building design process. Blismas et al. (2006) even came to the conclusion that most organizations do not have any formal methods in making comparisons or decisions between different building solution options, but that project decisions were made in unrecorded conversations and documented poorly in several different documents. Pan et al. (2012) concluded that even though striving for better methods, the evaluation and selection of building solutions is still often fragmented and cost-driven rather than value-based.

MCDM methods usually rely on different computational methods, so that pure heuristic evaluation would be diminished. Although these methods have proven to be effective in highlighting the indirect costs, they offer little insight on the dependencies and constraints of a specific building solution. These in turn are very difficult to evaluate computationally, as a dependency or constraint can have various effects depending on the affiliated building solutions (Cooke et al. 2008). Evaluation of these solution combinations could therefore be done by utilizing different decision-making methods that support heuristic evaluation. In order to gain a complete understanding of the impacts of the selection of a building solution, it seems that the different evaluation methods should be combined, so that the direct and indirect costs as well as the dependencies and constraints related to the solution would be clear. This is also not a new phenomenon, as found out by Marttunen et al. (2017). In their research, the combined use of MCDA methods and Problem Structuring Methods (PSMs) was analyzed, concluding that there are several combinations made but little knowledge of which combinations work best in different decision situations. An example of this is a research by Cooke et al. (2008), where a web-based decision support tool to integrate the occupational health and safety risk into the design process was developed with the use of argument trees to represent experts’ knowledge. This type of combination of a visual tool, such as the argument trees, to a MCDM method was seen feasible, as all the possible scenarios were easily found and documented. (Cooke et al. 2008) The problem with the current methods is though that they are extremely specific,
designed for instance to choose a heating method or a type of foundation. The methods also focus on comparisons rather than the attributes of a specific solution. Structuring the value tree of the problem as well as combinations of different methods were also concluded to require further research. (Marttunen et al. 2017)

### 3.1.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a widely used decision-making method in the AEC industry (Arroyo et al. 2014a), that aims in breaking down a complex problem into parts in a hierarchic order and determine which variables have the highest priority and should be addressed in order to influence the outcome of the problem. The hierarchic structure is used to provide a visual decomposition of the problem that gathers expert opinions and tacit knowledge in an easily understandable form. AHP is an effective method in analyzing the selection of building solutions, as it visually represents various criteria and the sub-criteria associated with them, it can represent both quantitative and qualitative measures and the method is flexible which makes it easy to apply to various cases. AHP is based on pairwise comparisons, that can be done either on a relative linguistic scale or by numerical values.

![AHP hierarchy structure](image)

*Figure 11 AHP hierarchy structure. (Oguztimur 2019)*

AHP consists of three steps that are forming the hierarchy structure, making the pairwise comparisons between all the alternatives and finally the decision phase, where the best alternative is selected based on the ranking of the comparisons. The constructed hierarchy involves three levels, where at the highest level is the goal or the problem at hand, the different criterion or aspects at the mid-level and the identified alternatives at the sublevel (Figure 11). Usually the AHP method involves assigning numerical weights to the pairwise comparisons, so that each pair is evaluated separately and the degree of preference over one factor over the other is determined. These weights are gathered in a matrix form, that is used to determine the percentage importance of a certain alternative.

Comparison of the AHP method with the selection process presented in Figure 9, reveals that the method includes the goal formulation, generation of alternatives and a value-oriented assessment between the alternatives. The criteria, that are based on the goals and constraints set by the stakeholders and gatekeepers are restricting the available alterna-
tives. The method does not though take into account the impact analysis of the alternatives, and therefore fails to identify any dependencies and constraints that the alternative solutions may set on other solutions. Even though one alternative might seem superior based on the criteria in the evaluation, it might be that the solution requires the use of another solution which performs extremely poorly regarding the set criteria. Therefore, the solution combination may be a worse alternative than the combination which another alternative would have produced.

There are also other problems related with the AHP method. The pairwise comparisons are evaluated by their degree of importance, which may in some cases be extremely difficult or without actual meaning. For example, valuing the fire safety over acoustic performance does not have clear meaning and could distort the results in an unfavorable way. The comparisons are also done subjectively, without defining which factors affected the decision and to what extent. The computational requirements become very large even for a problem with a few alternatives, since all of the alternatives need to be compared pairwise. These comparisons can also be project or analyst dependent, which makes reuse of the model difficult. In an extensive problem, building the hierarchies can consume a lot of resources, but on the other hand once constructed, it can be reused even though the pairwise comparisons would be redone. Even though the selection process (Figure 10) indicates that the goals and preferences are formulated before generation of the alternatives, restricting the alternatives based on the criteria might generate problems if the identified criteria are not exact, such as meeting a certain value in a specific criterion. Therefore, qualitative criteria might be extremely hard to implement.

3.1.2 Choosing by Advantages

Choosing by Advantages (CBA) is another widely used decision-making method, that is mainly found in the Lean construction literature (Arroyo et al. 2014a). It compares the advantages of different alternatives and bases the decision on the alternative with the most advantages. The CBA comparison can be done with various tools, but generally a spreadsheet program is utilized, such as Microsoft Excel. The CBA process (Figure 12) is divided into seven phases, beginning with the identification of alternatives. After this, the factors relating to the alternatives are defined. The factors are issues that influence the decision-making, for example relating to appearance, safety or quality of the alternatives. Cost cannot be a factor as it is evaluated separately in the end of the process. The third step deals with defining the criteria, such as the faster the better (as for example a criterion for installation) or the higher the better (as for example the recyclability content of the material) and are decided subjectively. After this, the attributes of the different alternatives are described based on the previously defined criteria. The fifth step constitutes of defining the advantages based on the criteria of each alternative by comparing them to the worst available alternative. The alternative identified to perform worst in the specific criteria does not have an advantage over the other alternatives and is therefore left blank. After this the importance of each advantage is decided based on their value creation on a scale of 0-100, where 100 is assigned to the advantage of the greatest significance. Lastly the alternatives are evaluated in relation to their costs, so that the budget restrictions can be accounted with relation to the value generated by the alternatives. The process may end here or start over with reconsidering the alternatives, after which all the process steps are repeated. (Pekuri 2015)
The CBA method covers almost all the phases in the selection process of building solutions. The goals and preferences are formulated in the form of criteria, where certain minimum requirements for the performance of the alternatives can also be easily set. Unlike in the selection process description and the AHP method, in the CBA method the alternatives are identified first followed by the definition of the criteria. Even though the order is not that important, the CBA method allows a better consideration of also qualitative criteria, as the alternatives can be organized according to the extent the criteria is met, rather than restricting the number of alternatives. In addition to problem formulation and alternative generation, the CBA method also strives to assess the value of the alternatives rather than just the costs. However, as for AHP, neither CBA highlights the dependencies of a building solution but only the immediate qualities of that solution and therefore fails to analyze the impacts of the different alternatives. Therefore, the selections made based on this method can also lead to unplanned disadvantages such as cost overruns and disfavored solution combinations. The advantage of CBA method is that it clearly describes the attributes and advantages of the different alternatives, documenting also the steps leading to the decision. Thus, the factors that lead to the decision can be traced by others as well, providing better opportunities for the whole project organization.

### 3.2 Modular construction

A great deal of the research on selection of building solutions has dealt with comparing and justifying the use of modular and prefabricated solutions, because these usually hold a lot of indirect effects that are hard to reveal with traditional selection methods, and that in fact often justify their use over traditional on-site built solutions. Because complexity is also typical, a direct comparison of components is usually not possible. Many re-
searches also argue that the reason behind the slow uptake of prefabricated building solutions is in the traditional material, labor and transportation cost-oriented evaluation methods that disregard many costs arising in the production and usage phases (Pasquire & Gibb 2002, Blismas et al. 2006). Value-based methods are therefore often suggested as a means to compare prefabricated building solutions to onsite production.

In literature, the terms prefabrication, preassembly, modularization and off-site manufacturing are often mixed, and their boundaries blurred (Gosling et al. 2016). Modularization is a broad concept with various interpretations and meanings in research and different sectors. Even though there are many definitions, modularization is often understood as simplifying of a complex product or process by dividing it to distinct parts that are self-sufficient and independent and are connected to each other by standardized interfaces. These parts of a modular system are often referred as modules. (Miller & Elgård 1998, Gosling et al. 2016) Prefabrication is closely related to modularization, as often modules are fabricated outside the final building site and only assembled or connected to affiliated parts onsite (Ballard & Arbulu 2004). Preassembly refers to joining of prefabricated components to form a building system or a complete building. It can be done either onsite or offsite before installation of the system. Off-site manufacturing includes both prefabrication and/or preassembly and is often used as a more generic term of these two. (Schoenborn 2012)

Traditionally, buildings have been divided into segments based on the different trades such as frame, plumbing, electrical works and so on (Bertelsen 2005). Modular building or modular construction on the other hand refers to a building consisting of self-supporting modules that are joint together and built on top of a foundation. Modular building can cover many strategies including the use of modular units that comprise a specific space such as bathroom modules, modular building parts such as wall elements with integrated technology or modular technical elements such as building service systems elements or air-conditioning rooms. (Peltokorpi et al. 2018b) These modules can be highly complex internally and involve the expertise of many different trades, as long as the interfaces are simplified and standardized. (Bertelsen 2005)

Modularization is argued to reduce complexity of the building and its design, as the dependencies between the different components are reduced (Tee et al. 2019) Therefore, it can be seen as a method to control the dependencies and constraints between building parts. Modularization also enables prefabrication and simultaneous development of product parts or modules, which reduces the overall construction time (Peltokorpi et al. 2018a, Peltokorpi et al. 2018b) This enables effective use of Concurrent Engineering (CE) or SBCE in practice. Although modularization reduces the need for project specific design as existing design solutions can be utilized, it requires early involvement in the design process in order to produce plans that support the use of modules (Aapaoja & Haapasalo 2014, Peltokorpi et al. 2018b). However, even though some dependencies might be reduced, others might be created as the modules might set restrictions on the installation order of building parts or the way the different parts interact with each other. Therefore, a thorough impact analysis cannot be disregarded even with modular solutions. Modularization generally reduces the need for design changes during construction, as many problems can be addressed inside the module without affecting the affiliated building parts (Peltokorpi et al. 2018b). As there are fewer changes, cost certainty is better from the start of the project, which benefits the whole project organization. (Blismas et al. 2006, Pan et al. 2007) On top of these, most of the benefits are realized in the construction phase, where quality, efficiency, safety and schedule benefits become visible. (Peltokorpi et al. 2018b)
Modular building promotes a Lean construction process where as Lean building and philosophy promotes the use of modular building components. (Aapaoja & Haapasalo 2014) Therefore, Lean construction and modularization is often believed to go hand in hand. Modularization is generally simplification of the product, which from a Lean perspective can be seen to diminish waste and create value in the form of better quality and process flow (Bertelsten 2005). This simplification is though also viewed as a downside of modularization, as it reduces variability and the customer’s ability to affect the designs. As customers are mostly interested in visible attributes and functionalities, focusing on providing variability in them and standardizing the technical solutions including interfaces is seen viable. (Pelkonorpi et al. 2018b) Modularization does also not mean that all variability and customer tailoring would be neglected. There are even views that modularization increases product variation, as altering the order of the modules or the components in them basically creates new products. (Ulrich 1995) This form of choosing the components that the customer prefers on a base model containing the necessary parts is called mass customization. (Bildsten 2011)

3.2.1 Modular product architecture and management of component interfaces

Modular product architecture is a term that refers to the way the different functions or actions in a module are aligned into physical components. Unlike in integral product architectures, a module product architecture is comprised of independent sub-assemblies that are connected with each other with standardized interfaces. (Ulrich 1995) According to Ulrich (1995), the component interfaces can be divided into three categories that are slot architecture, bus architecture and sectional architecture (Figure 13).

![Figure 13 Component interfaces. (Ulrich 1995)](image)

In slot architecture, the interfaces between the components are all different from one another, which prevents interchanging of the components. Typical slot architecture elements include modules which dimensions may change, as for example a wall element where the alteration of the length is typical. In bus architecture, the interfaces are all identical connecting to a common bus component. This type allows swapping the places of components and offers thus more freedom than slot architecture. (Ulrich 1995) In construction, a foundation where different types of wall elements are installed, can be considered as a bus architecture (Jensen et al. 2012). In sectional architecture all the interfaces are identical, which enables placement of the components in any order. (Ulrich 1995) This type of product architecture can be utilized in volumetric and prefabricated modules (Jensen et al. 2012). Often though one modular system holds several different types of product architectures and the perceived type can vary at different levels (Voordijk et al. 2006).
Standardization of interfaces holds several different benefits. It makes product control easier, as parts of the product can be changed and developed individually keeping the interfaces constant. Because of this, certain freedom in design exists inside the components. Moving towards a more sectional product architecture makes the selection of components easier, as the decision can be based on the internal attributes rather than on the dependencies and constraints other building parts set. Greatest focus in the construction industry should therefore be put on the standardization of interfaces, rather than on the components themselves (Aapaoja & Haapasalo 2014, Berstelsen 2005)

### 3.2.2 Degree of modularization in the construction industry

The degree of modularization can be divided into four categories that are represented in Figure 14. Traditional construction is furthest away from complete modularization, with only subcomponent level of modules, such as bricks and beams that are both manufactured and assembled from materials onsite. The second level involves modular components, such as heat generators and radiators that are installed onsite. The third level involves volumetric modules such as bathroom modules that are manufactured off-site and installed onsite. Full modularization involves manufacturing of the whole building off-site and only positioning it onsite. (Gosling et al. 2016)

![Figure 14 Degrees of modularization. (Adapted from Gosling et al. 2016)](image)

Modular construction is becoming more popular in Finland, and it is believed to increase the productivity and at its best, improve the quality of construction. (Kauppalehti 2018) Even though modularization is not new, but several different components and subcomponents are widely used, modular multi-story construction is still absent in Finland. (Sorri 2013) Most commonly the degree of modularization is somewhere between component
and element levels, with some elements, such as building service system modules and bathroom modules used. Currently modular construction is mainly used in small residential buildings such as detached and semi-detached houses, challenging complementary or extension building such as additional stories to existing buildings and construction of temporary buildings. (Kotilainen 2013)

Modular construction approaches are seen as a solution to many persistent problems in the construction industry, but the uptake of them is still slow. (Kotilainen 2103) Attitudinal issues and the lack of practical guidance are seen as barriers hindering the uptake, as effective methods to show the actual costs do not exist. (Gosling et al. 2016) Also the lack of compatible systems hinders uptake of modular solutions as modifying them so that they fit with rest of the building solutions is only perceived to add cost and complexity, rather than eliminating it. Now when the industry is still moving towards a greater degree of modularization and only some of the solutions and interfaces are standardized, the full benefits of modularization can be hard to realize. Because of this, in order to realize the full benefits of modular construction, a situation with fully modular systems and high standardization should be strived for, so that onsite activities would include mostly assembly activities rather than manufacturing from raw materials.

### 3.3 Off-Site Manufacturing

Off-Site Manufacturing (OSM) refers to prefabrication of building components that is carried out in an offsite factory environment. OSM involves manufacturing and assembling of buildings or building parts beforehand that in traditional construction would be constructed onsite. Although modularization and prefabrication are often seen to go hand in hand, modular building systems do not require prefabrication even though usually that is the most preferred manufacturing method because of its benefits. (Gibb & Isack 2003, Elnaas 2014)

Prefabrication is currently seen as the most promising means of boosting the productivity and value generation of the construction industry. (Aapaoja & Haapasalo 2014, Raunama 2015) As production can be moved into a controlled environment in factories, the quality is improved, costs are reduced and the construction time onsite is reduced (Peltokorpi et al. 2018a). This is often linked to Lean practices, as this type of production method further the creation of a value-oriented process flow compared to the construction work tasks performed on site and the waste generated by it (Aapaoja & Haapasalo 2014). Aapaoja & Haapasalo (2002) concluded that waste could be reduced by nearly 85% with prefabrication compared to traditional construction. Prefabrication though requires more extensive design, as all issues need to be solved beforehand because no changes can be made in the design based on the difficulties identified in the construction phase. (Pel-
tokorpi et al. 2018b) As the current design process is constantly adding level of detail and highly iterative, it is not suited for the use of prefabricated solutions. Therefore, the whole design process should be made more front-end weighted, and the prefabricated solutions taken as a perquisite for other solutions, rather than adapting prefabricated solutions to fit existing plans. (Aapaoja & Haapasalo 2002, Gibb & Isack 2003) Other costs relating to prefabrication include greater transportation costs, as the assembled products cannot be packed as densely as the composed materials could be packed. Prefabricated solutions can also require more machinery, such as cranes and skilled workforce. (Smith 2010) Therefore the technical price of prefabricated solutions comprised of these factors is often greater than of traditional construction methods.
Even though the benefits of OSM seem to be widely known, the decisions regarding the use of OSM in building projects is still unclear and complex. As for selection of other building solutions, also the use of prefabricated solutions is often based on opinions and experience rather than actual data. (Bismas et al. 2006) As the benefits of OSM are in the value aspects and the cost reductions are achieved by indirect cost savings, the potential can be hard to perceive by traditional evaluation methods. There have been several attempts to compare prefabricated solutions with traditional building solutions. Especially in several theses, comparison of bathroom modules to traditional onsite built bathrooms has been widely researched, but the effect of indirect costs has not been proven and the evaluation has been based on direct costs and effects on project schedule (Sorsa 2012, Myyrä 2012, Jokivuori 2014), or the researcher has concluded that there most likely exist indirect costs that would affect the outcome but evaluation of them is difficult (Sundell 2015). Hence there is still a need to improve the methods of evaluation, so that all aspects could be considered and justified.

3.4 Standardized processes and products

Standardization refers to the repetitive use of products, processes or methods in reoccurring situations (Gibb 2001). Standardization is not actually new in the construction industry, but several different components, starting from bricks and steel beams have been standardized for years. Where as many researches propose thinking of the construction projects more like standardized processes and products in order to reduce waste, there are also drawbacks, as the more standardization occurs, the less customization can be made. Therefore, ideally standardization should be applied in the interfaces of the products, ensuring compatibility between the components and mitigating design work. (Aapaoja & Haapasalo 2002, Gibb 2001)

In construction research, standardization of processes has received a lot of attention. Aapaoja & Haapasalo (2002) claimed that there is not much use of standardized products or components, if the production processes are not standardized. Following the same logic, Höök (2008) proposed that traditionally unique construction projects should be viewed as standardized processes, where the production processes and pace would be constant independent of the project. This would enable better estimation and evaluation of the project’s success, as the ability to measure, understand and control different variations is crucial for the success of the project and process control. (Aapaoja & Haapasalo 2014)

Standardization is often applied simultaneously with modularization and prefabrication, as they support each other. Standardized and foreseeable processes are seen as the main enablers of Lean culture in the construction industry and prefabrication and modularization should be based on standardized processes in the design phase so that all its benefits could be utilized. (Höök 2008, Aapaoja & Haapasalo 2014)
4 Summary of literature review

The literature review focused on two main themes that included the overall construction design process and the selection of building solutions. The aim was to develop an overall understanding of the design process as well as the selection process of building solutions, and to map out the methods already developed to support these processes. The literature review started off with describing the overall construction design process and the effects of it on project quality and costs in chapter 2. By identifying the aspects affecting the project outcome, an idea on the selection criteria of building solutions was established. Reviewing the characteristics of the design process and tasks enabled to clearly understand the overall process and its demands and restrictions. The role of design management was identified, and the current tools used to support the design process were mapped out. In the third chapter, the review focused on the selection process of building solutions in particular, and the problems and shortages in that process were identified. In addition, modular construction and its features was studied to further understand the selection process and the special demands modular solutions sets on it.

The first research question how could the dependencies and constraints as well as the direct and indirect costs of a building solution be identified and documented? is addressed with mapping out the current decision-making methods and their qualities. The current methods are still often fragmented and cost-driven rather than value-based, which has led to surprises in projects in the form of unanticipated indirect costs. As the dependencies between the different building solutions are often complex, accounting these indirect costs to be part of a specific solution has failed, and costs have been reported under operating and joint costs. This in turn has amplified the unawareness of the true origin of costs and learning in the selection criteria has not occurred. The identification and documentation of costs can therefore be concluded to be insufficient and should be done in a way that cost knowledge of the building solutions including the indirect costs would be visible throughout the project, also to the designers. Different kinds of hierarchy models have proven to be efficient in presenting this type of tacit knowledge.

The design process is often restricted by budget and time constraints, which means that a balance between exploration of alternatives and decisions must be found. Different methods have been developed to aid in the process control and formulation of task dependencies, but no guidelines exist on how thoroughly alternatives should be explored. Because of this, the degree of exploration of alternatives and their impacts depend on the design team and the Design manager. In Finland, most of the problems with the design phase deal with the flawlessness, compatibility and consistency of plans as well as cost awareness. On the other hand, the competency of the designers is seen to be very good, which implies that the problems are mainly related to the process that does not utilize this competency.

Literature suggests initialization of modular solutions in the construction industry to achieve better predictability in the projects and to reduce the dependencies between the different building solutions. There are two different types of dependencies between the building solutions. The first type deals with the requirements and restrictions that the building solutions generate to one another. These dependencies might deal with aspects like structural stability or functionality. The other type of dependency is dealing with the order of tasks, that is the installation order of the building solutions. Even more, the different solution combinations can produce new dependencies of either type. The more sectional the product architecture is, the more dependencies between the building solutions
are diminished. The construction industry is though still somewhere between component and element level of modularity, which means dependencies of both types still exists. The methods taking into account dependencies and constraints between building solutions, in other words performing an impact analysis, are extremely insufficient. Although BIM models and different parametric tools are used to ensure the constructability and structural stability of a building, further impact analysis is basically nonexistent.

The second research question *what are the viewpoints that need to be considered during the selection of a building solution? Which project parties should be involved?* was explored by identifying project success factors and the aspects that are considered in the current MCDM methods. The project parties involved in the process were identified by exploring the design and selection processes and their phases. Both the success factors and the current aspects of consideration comprise of many issues, that are often seen to cluster under three themes that are environmental, social and economic aspects. The aspects that are considered vary depend on the person doing the selection as well as the solution under review, which means that no consistent viewpoints exist. The project parties involved in the design process and selection process of building solutions includes stakeholders such as the customer or contractor, gatekeepers such as the authorities, designers as well as decision-makers such as the design managers or customer but can also have different roles depending on the project delivery method. Because of this, also the parties that are involved in the selection process might vary.

The third research question *what aspects should decision-making on building solutions be based on?* is also explored by reviewing the current decision-making methods as well as project success factors. Often success of the project is considered from only three aspects that are cost, schedule and quality accuracy but various other aspects such as life cycle performance and health and safety aspects are becoming increasingly more important and thus included in the decision-making factors. The conclusive decision is often based on costs that include immediate material, labor and transportation costs. As the aspects considered vary depending on the person and situation, also the decision-making criteria are different depending on the situation. Due to the budget and schedule constraints of the projects, a pressure to make decisions to keep the design process moving forward is often evident and conducting extensive evaluations of different alternatives is usually not possible. Decisions are also often based on previous knowledge and assumptions, and thus the most feasible alternatives might not be identified at all or disregarded due to faulty criteria.

The selection of building solutions is an extremely complex process, where the building solutions set constraints and dependencies towards one another, and thus the entirety has to be considered at all times. This is contradictory to the overall process, where the level of detail is seen to accumulate as the process moves forward, building on the previous decisions. Understanding the entirety and the impacts of the solutions is often seen to be based on experience, and no real methods have been developed that aim in supporting this phase of the selection process. Because of these gaps in the impact analysis, an unexperienced project manager or customer still selects building solutions that seem to be the most cost efficient, but in fact hold a lot of indirect costs. This is also the reason for the slow adaptation of modular solutions, as their cost efficiency has not been able to be proven.

In Figure 15, the selection process of building solutions is presented starting from problem formulation, after which alternatives are generated and these alternative building solutions considered. As the current practices are varying, some decision-makers base their
selection only on the direct costs of the specific solution, such as the immediate material, labor and transportation costs. In addition, various amounts of impact analysis and value-based assessment is made, from where various indirect costs such as costs relating to safety, easiness of execution or the life-cycle of the solution can be discovered. As these costs may have a significant impact on the total costs of the solution, the selection process should include both considerations. The impact analysis and value-based assessment might also result in various noncomputational factors, but since these are hard to define precisely, the considerations often remain experience based and relying on assumptions of the decision-maker. Therefore, the more subjective aspects are often unnoted or overlooked by the direct cost considerations.

Figure 15 Selection of building solutions based on literature.
5 Review of current situation in the case company

In chapter 4, the findings of the literature review were summarized. The literature concerning construction design and the selection process of building solutions was explored and evaluated, and the gaps in the current methods were identified. In this chapter, the current design and design management in the case company is reviewed, and the problems in that process are identified. The used research approaches of this review are first introduced, after which the analysis and evaluation of the material are presented.

5.1 Research approach

The existing design and design management at Fira was mapped out in three different, mostly qualitative approaches. The material on the current practices and their practicability was mostly gathered by conducting semi-structured interviews. In addition, the existing design and design management process and practices were mapped out by observing the ongoing design of a project by attending the design meetings and Big Rooms. Thirdly, different documents of the company were analyzed, ranging from process descriptions to Big Room minutes and notes. This type of combining different perspectives in the analysis of the same event is referred to as triangulation, which was already recommended by Denzin (1978) in order to reduce the inherent bias of a particular data source and method. Triangulation has been since used by researchers to increase the validity of inference in qualitative and quantitative research. (Creswell 2014, Johnson et al. 2007)

The research approaches are generally roughly divided into qualitative and quantitative approaches in addition to mixed methods research that resides in the middle of the two. The approaches are though not rigid, but a research often tends to be more of one than the other and is therefore said to represent the particular approach. Hirsjärvi & Hurme (2008) argue that the selection of research approach is dictated by the research problem and its formulation. As quantitative research is based on analysis of often large numeric data sets, using the method is justifiable in situations where the extent or magnitude of a certain phenomenon is studied. A qualitative approach on the other hand is used when the aim of the research is on understanding a certain phenomenon, and often answers how and when questions. Qualitative research approaches, such as interviews and participant observation are also feasible when the experiences and observations of examinees are being studied and when tacit knowledge is believed to exist. (Saaranen-Kauppinen & Puusniekka 2006, Creswell 2014)

In the review of the current situation in the case company, a qualitative research approach is selected. This is supported by the fact that the aim is above all to understand the current process and its problems, and the information is held by people involved in the process. As the desired outcome is a refined process, rather than for example specific numeric values on the quantities of selected building solutions, the use of a qualitative approach is justifiable.

5.1.1 Selection of research methods

A qualitative research approach often involves data collection in the participant’s setting. (Creswell 2014) Hirsjärvi & Hurme (2008) identify interviews as be best suited in cases where mapping out the current situation is pursued or when information is based on the experience and knowledge of the interviewee. As this is exactly the case with this part of the research where the current process in the company is mapped out in order to make a suggestion, using interviews as the primary source of material is justified.
There are several types of interviews that are often classified according to the degree of predefined structure in the interview, in other words how accurately the questions are formulated and structured and how much room is left for the answers of the interviewee. (Saarinen-Kauppinen & Puusniekka 2006) Interview types can be roughly divided into three categories that are structured, semi-structured and open interview. A structured interview is the most formal and is equivalent to a survey with predetermined answer options and identical questions for all participants. On the other end, an open interview is the most informal, resembling a free conversation with open questions that can be modified and presented in any order based on the course of the interview. In between these lies the semi-structured interview, that is more structured than an open interview with predetermined themes that are followed, but the questions themselves and their order can vary. (Hirsjärvi & Hurme 2008) This informality in the structure supports surfacing of interpretations and opinions of people while still being able to control that certain themes and subjects are being covered, and thus serves best the needs of the suggestion formulation. On the other hand, this type of interview method requires extensive knowledge also from the interviewer in order to be able to keep the focus on the right themes (Saarinen-Kauppinen & Puusniekka 2006). The researcher has formed a good overview on the subject prior to the interviews by conducting a thorough literature review, which enables proper structuring of the interview themes and conversation of the emerging aspects.

In addition to the literature review, the researcher participated in the design meetings and Big Rooms of an ongoing project in the case company to gain knowledge on the existing practices. Besides forming an overview on the subject for the interviews, this participant observation also served as a material collection method. Hirsjärvi & Hurme (2008) define participant observation as both organized and unorganized informal data collection. Because the objective of this phase was to map out the current situation without yet making suggestions, a passive role in the design meetings and Big Rooms was adopted. In addition, several documents of the case company were studied. The minutes and other notes of the design process of a project was studied to formulate the decision-making procedures and level of documentation. In addition, the current process descriptions were studied to understand the design process and the responsibilities within at Fira. As the researcher partly worked from the head office of the case company, participating in the everyday conversations in the hallways as well as different training days could also be counted as participant observation, helping in formulation of the current practices in the company. As observation is subjective and the remarks made are highly based on the individual, this form of material collection can be seen to have many limitations. On the other hand, it can be seen to help in the formulation of deductions by supporting other findings.

5.1.2 Material collection and analysis

A major characteristic of material collection in qualitative research is expedient samples. This means that the material and the examinees are selected based on certain criteria set by the researcher. Saarinen-Kauppinen & Puusniekka (2006) conclude that in semi-structured interviews, such interviewees should be selected from which material on the subject of interest is believed to be best attained. The same method is applied to the analysis of existing material, where the Big Room minutes and notes of a project that is believed to hold typical documentation are examined.

The interviewees were selected from eight different pre-identified groups that are accounting, production, design management, development, environment, procurement and quality/warranty. The groups represent the different departments in the company that are
believed to be involved in or influenced by the design process and the solutions made. This assumption is based on the Project success theory by Chan & Chan (2004) presented in chapter 2 as well as Fira’s process descriptions on the design phase of residential construction. During the interviews the involvement of these groups and the influence of the design solutions in their work is verified. One interviewee per group was selected, based on the availability of the personnel. Most often a manager level person was selected, as they were presumed to hold the broadest view on the current situation of the processes. In the interviews possible future interviewees were also surveyed by asking the interviewees who else in their opinion should be interviewed regarding the subject. This form of choosing interviewees is often referred to as snowball sampling, that is often carried on as long as new information presents on the subject (Hirsjärvi & Hurme 2008). Because there were eight groups identified in the first stage, following the method exactly would have produced an extensive number of interviews and therefore the suggestions were fulfilled only if a new group (or a distinct new part inside the group) rather than a new person was identified. The interviewees and the information on the interviews are presented in Table 1 below, where under round 1 are found the first eight interviewees and under round 2 the additional four that were identified based on the suggestions of interviewees in round 1.

### Table 1 Interviewees.

<table>
<thead>
<tr>
<th>Group</th>
<th>Designation</th>
<th>Duration (min)</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Round 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accounting</td>
<td>Accounting manager</td>
<td>53</td>
<td>I1</td>
</tr>
<tr>
<td>Production</td>
<td>Construction manager</td>
<td>68</td>
<td>I2</td>
</tr>
<tr>
<td>Design management, residential construction</td>
<td>Design manager</td>
<td>53</td>
<td>I3</td>
</tr>
<tr>
<td>Development</td>
<td>Senior Residential Developer</td>
<td>62</td>
<td>I4</td>
</tr>
<tr>
<td>Environment</td>
<td>Environment manager</td>
<td>75</td>
<td>I5</td>
</tr>
<tr>
<td>Procurement</td>
<td>Procurement engineer</td>
<td>35</td>
<td>I6</td>
</tr>
<tr>
<td>Quality / warranty</td>
<td>Quality manager</td>
<td>38</td>
<td>I7</td>
</tr>
<tr>
<td>Management</td>
<td>Category manager, project planning of residential construction</td>
<td>39</td>
<td>I8</td>
</tr>
<tr>
<td><strong>Round 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design management, solution development</td>
<td>Design manager</td>
<td>48</td>
<td>I9</td>
</tr>
<tr>
<td>Quality / warranty</td>
<td>Project manager, warranty period</td>
<td>45</td>
<td>I10</td>
</tr>
<tr>
<td>Production</td>
<td>Project manager, residential construction</td>
<td>46</td>
<td>I11</td>
</tr>
<tr>
<td>Design management, residential construction</td>
<td>Project planning manager, Verstas manager</td>
<td>62</td>
<td>I12</td>
</tr>
</tbody>
</table>
The interviews focused on five themes:

- Introduction on research and background of interviewee
- Existing standardized solutions in Fira
- Consideration of dependencies and constraints in selection of building solutions
- Consideration of costs in selection of building solutions
- Additional comments, feedback

The complete structure of the interviews can be found in appendix 2. The same structure was used in all the interviews and all the themes were somewhat covered with all the interviewees. However, the depth of the coverage varied between the interviews based on the answers of the interviewee. The questions were divided into three levels, so that the first level included a fairly general formulation on the matter, followed by detailed questions on the second and third levels. If the interviewee was seen not to possess any more information on the matter after the first level, the detailed questions were not introduced. This allowed the interviews to focus on the themes that the interviewee had most information on, still allowing articulation of opinions on all the themes. Even though the interview structure holds specific questions, these were not slavishly followed but new questions could emerge, or the formulation change in the course of the interviews.

The chosen themes are not only linked to mapping out the current situation, but also directly to the research questions. Therefore, besides discussing the current state of processes with the interviewees, insight on how to better identify the dependencies and constraints as well as the direct and indirect costs of a building solution (RQ1) was covered. Also, the current viewpoints affecting selection and the project parties involved, as well as the viewpoints and parties that should be more extensively affiliated (RQ2) were discussed. Decision-making (RQ3) was not covered as its own topic, but it was covered alongside with viewpoints that need consideration in general.

The interviews were conducted by the researcher in November and December 2018. All the interviews were conducted as personal interviews face to face. The interviews were conducted in Finnish, that is the first language of the interviewer as well as the interviewees. The interviews were recorded, for which permission was asked individually from all the interviewees in the beginning of the interview. After the interview, the tapes were transcribed by the researcher as soon as possible, most often during the same or the next day. The transcription was done as a basic level transcription where all speech is transcribed but fillers and non-lexical sounds are left out (Hirsjärvi & Hurme 2008). The transcription was done in a word processing software where both the interviewers as well as interviewees comments were noted.

After all the interviews were conducted and transcribed in documents, analysis was carried on with a spreadsheet software, where the shortened responses of each interviewee were categorized under themes. These themes followed the themes of the interview structure. The responses were analyzed by themes, so that patterns and recurring answers were looked for and clustered in a summary. The responses were though always connected with the interviewee, so that no information on the background would be lost.

In the analysis of material, an abductive reasoning process is utilized, that combines inductive and deductive reasoning (Hirsjärvi & Hurme 2008). Inductive reasoning is based on generalization where a theory is formulated based on a set of observations. Deductive
reasoning on the other hand progresses from a general theory into details using known facts. The abductive reasoning process (Figure 16) combines prior theoretical knowledge and real-life observations, from which a theory suggestion is formulated with the use of theory matching. (Dubois & Gadde 2002, Kovács & Spens 2005) In this research the theoretical knowledge is gathered through the literature review that gives readiness to the researcher to make focused observations. The formulation of the interview questions, analysis on the interviews and observations from the design meetings and Big Rooms were all done so based on the findings of the literature review and on the other hand the literature review could be supplemented with the findings of the interviews. The literature review and collected material is thus supporting each other, rather than being separate entities. In the context of DSR, this form of knowledge gathering, and formulation is necessary and supports the nature of the research methodology.

![Abductive reasoning process](image)

5.2 Existing design and design management process and practices at Fira’s residential construction unit

The main forms of building contract work in Fira is DB and MC, and the design work is bought from other companies whilst Fira is in charge of design management of the project. Fira does not do own development projects, but contracts projects for customers, mainly for developers doing rental housing. Fira is also fairly new in residential construction with only 18 completed projects so far. (Fira 2019)

The design process in a typical DB residential construction project in Fira can be divided into two parts that are project development and construction design (Figure 17). In addition, before these, the city plan requirements and the initial project plans are developed where the required cost-effectiveness of the project is ensured. In project planning, the project plan is put together, and the profitability calculations are made. Fira has developed a special form of project development called Verstas (in English workshop, carpenter’s shop) that is an interactive concept that gathers all the project parties around the same table. Project development is done either according to the Verstas model or as normal project development. In the options appraisals phase, the plans of the building are developed so that they are efficient in terms of the key ratios and cost as well as constructible. The plans also need to consider usage of Modules bathrooms whenever possible. The phase produces floor plans of the building. Up to this stage, the project development manager, or as called in Fira Verstas manager, has been in charge of the project. Depending on the project, a Project engineer could be also involved in these phases assisting the Verstas manager. A Design manager is also involved in these stages as an expert ensuring
that the produced designs are of adequate level of detail and that the selected solutions do not include matters that lead to unexpected increased costs in the later stages of design and production. The Design manager uses different experts from the solution development and building service systems teams as needed. (Fira 2019)

Figure 17 Design management responsibilities in Fira.

From the concept design phase onward, the Design manager is responsible for the design management of the project (Figure 17). In this phase, the designers are chosen and the initial schedule for the design phase is made. Cost accounting is started, and the feasibility of the project is reassessed. After this, the plans are developed in such an extent that the building permit can be applied. In the construction design phase, the detailed design takes place. The Design manager leads the design that takes place in design meetings or Big Rooms and is responsible for the adequate level of the designs as well as keeping record of the decisions and progress of the design work. The BIM models need to be up to date and consistent so that no collisions take place. The responsibility on the design management is on the Design manager until jointly is agreed that rest of the tasks can be transferred to the Site engineer in the construction phase. Usually this takes place after the designs are once accepted and only minor detailed design is left. (Fira 2019)

The current sharing of responsibility is rather new in Fira and the task descriptions were just published at the time of this research. Simultaneously, a new gate model was introduced, where the design process was divided into eight phases each containing a gate with certain requirements that must be met in order to be able to move on in the process. The residential construction design process was also described in detail, with specific tasks and task descriptions throughout the design process. (Fira 2019) As these processes and task descriptions were not fully been taken into practice when conducting the interviews, the typical challenges of the design management were believed to be dealing with the absence of clear process descriptions and systematics (I2, I4, I6, I10, I11, I8, I12). Because of no common way of acting, the opinions about the current process and practices were varying among the interviewees. Also, the quality of the design and design management was experienced as varying and dependent on the Design manager leading the design process (I4, I9, I5, I7, I11, I8, I12).

5.2.1 Standardized solutions

There were different views about the current state of standardized solutions in the company. Some informants (I9, I5) believed that the solution library of the company was extensive enough but not used as much as it should. Most of the interviewees though thought that despite there are some standardized solutions in the company, a solution library does not exist (I1, I2, I3, I6, I7, I11, I12). The bathroom module Modules (I1, I9, I5, I6, I7, I10, I11, I8) and cube balcony Noppaparveke (I1, I3, I4, I9, I5, I6, I11, I8, I12) were most often mentioned when speaking about standardized solutions in the company that are strived to be used in the residential construction projects. The development of the
solution library is a working process, but the ongoing changes in the organization’s information systems have delayed it (I3, I4, I8). Because of this, at the moment the information is scattered, and people are struggling to find the right information even if it would be available somewhere (I1, I3, I12).

Fira is fairly new in residential construction and this lack of experience is seen as the main cause for the various problems in the projects (I1, I5, I11, I8). The lack of experience has been seen as mistakes both in the design as well as construction phases by not knowing how to design something right or how to implement it correctly on site (I1, I3, I4, I9, I7, I8). Some informants (I1, I8) also point out that the projects done so far have been quite different and demanding and that is why repetition and learning has not been able to take place. Some informants (I9, I8) also believe that one of the major issues is that every project is started from scratch and the existing solutions are not utilized as they should.

Generally, the interviewees believed that the variance of the projects should be taken under control and the extent of standard solutions and their usage should be advanced. A Fira way of doing residential construction should be found, and that model should be repetitively offered to the customer without question, unless there is something specific that the customer absolutely wants (I3, I4, I8, I12).

5.2.2 Decision making

As well as other processes, also the decision-making process has been lacking in Fira. As Fira contracts for customers, the decision maker in many cases is the customer. It is though on the responsibility of the person leading the design to present different solutions for the customer and guide the selection of solutions (I5, I8, I12). The development and consideration of different building solutions should take place as early in the project as possible (I1, I9, I7, I8). Revision of different solutions is not that structured at the moment but takes place in unofficial forms such as coffee table conversations (I1, I3). Gathering of information about the different or alternative solutions is mostly dependent on asking around from different experts in the company (I12) and the extent of comparing different solutions is based on the willingness of the person leading the design (I3, I12). Considering different alternatives and keeping options open is sometimes believed to take too long, partly because there is confusion about who should make the final decision or the choices on the solutions (I1, I3, I9). Because the customer does not usually care about things that do not show on the outside or are too technical for them to understand, the difficulty of decision making arises especially when dealing with solutions that are indifferent to the customer. Although the responsibility of the design process is defined in the process descriptions, some Design managers might be hesitant to make decisions on building solutions that affect the construction phase as there the responsibility on the solutions functionality is on the Construction manager (I12). Therefore, the involvement of the site personnel, such as the Construction manager or site manager from as early as possible is seen crucial in order to have the adequate knowledge on the actual consequences of the selected solutions as well as to get opinions about their preferences (I1, I2, I7, I11, I12). In addition, a more extensive involvement of the warranty and procurement teams is desired to achieve successful building solution choices (I6, I10).

As the selection of building solutions is currently done mostly based on subjective matters, it is believed that the selection should be based more on data analysis and the suitability and costs of a solution in the specific project should be analyzed further (I1, I4). The interviewees mention different aspects that need to be considered when selecting a
building solution, from which most often cost (I1, I3, I9, I5, I6, I7, I11, I8, I12), constructability / feasibility (I1, I2, I3, I4, I5, I6, I8, I12), effect on construction schedule (I1, I3, I4, I5, I6, I7, I10, I11) and the desires of the customer (I1, I4, I6, I12) are mentioned. The mentioned aspects in order of frequency are gathered in Table 2. In addition, some informants (I5, I7) mention, that even though the different aspects would be sufficiently covered, the weight of them should be considered further. Many of the interviewees though believe, that because the extent the aspects are considered depends on the Design manager, many bases their decision only on the consideration on a few of them. Some informants (I2, I11, I12) mention only a few selection criteria where as other informants (I1, I4, I5) mention many aspects that require consideration in the selection process. In general, the selection criteria can be seen to cluster around topics Fira has been struggling with such as unpredictable costs, difficult constructability and moisture and guarantee issues.
Table 2 Selection criteria of building solutions.

<table>
<thead>
<tr>
<th></th>
<th>Accounting</th>
<th>Production</th>
<th>Design management</th>
<th>Development</th>
<th>Environment</th>
<th>Procurement</th>
<th>Quality / warranty</th>
<th>Management</th>
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<tbody>
<tr>
<td></td>
<td>I1</td>
<td>I2</td>
<td>I11</td>
<td>I3</td>
<td>I9</td>
<td>I12</td>
<td>I4</td>
<td>I5</td>
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<td>Cost</td>
<td>x</td>
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<td>Constructability/feasibility</td>
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<td>Effect on construction schedule</td>
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<td>Desires of customer</td>
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<td>Moisture control</td>
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<td>Easiness of execution of the solution</td>
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<td>Expected guarantee costs</td>
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<td>Easiness of procurement</td>
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<td>Life cycle of the solution</td>
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<td>Technical quality</td>
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<td>Brand suitability (customer’s brand)</td>
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<td>Building circumstances, season</td>
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<td>Customer satisfaction</td>
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<td>Markability</td>
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<td>Regulatory provisions</td>
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<td>Safety</td>
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<td>Takt-time demands</td>
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5.2.3 Analysis of dependencies and constraints

As the challenges in the designs are believed to originate from the combination of different solutions rather than a specific solution on its own (I3, I10, I8), the analysis of dependencies and constraints in the design phase is extremely important. Drifting into non-optimal solution combinations has been a challenge in Fira, as the constraints and dependencies of building solutions have not been adequately identified in the design phase creating surprises and changes on site. Currently the analysis of the constraints and dependencies of a building solution is based on experience and the extent of it depends on the Design manager or project leader (I3, I9, I5, I11, I8, I12). The Design manager does the analysis mostly as a thinking process, taking into account the aspects that by experience is known to be connected with the solution, or by asking around from experts that might have knowledge on the matter (I2, I4, I5, I8, I12). The information is mostly comprised of tacit knowledge that is empirical and based on the craftsmanship of certain people (I4, I5, I7, I12). On top of this, the dependencies and constraints might also be hard to identify even with extensive experience because of the complexity of the product and changing execution environment (I1, I5, I11, I12).

Most of the interviewees consider that the constraint and dependency analysis done in the design phase presently is not satisfactory and should be improved (I1, I2, I4, I9, I5, I7, I10, I11, I8). On the other hand, because of the complexity of the analysis and the fact that every possible aspect cannot be considered, some feel that prolonging the design phase with more extensive analysis is not feasible (I3, I9, I12). Also, the limited time available for design is seen as one reason for not being able to extensively consider the effects of building solutions (I3, I12).

Standardized building solutions are believed to be the answer for better awareness on the dependencies and constraints of the building solutions as the repetitive usage provides realized information faster (I1, I3, I4, I9). Learning of design management in Fira has indeed been based on the feedback of the production phase (I1, I2, I3, I12). Because this method takes time and failures are bound to happen, a need for a more proactive reaction practice has been risen. As currently the designs are reviewed on the building site and necessary corrective measures are made there (I2, I3), the goal would be to have all the designs ready and workable already when starting the construction phase (I1, I4, I5, I10, I11). I5 further stresses that nothing should be left for the site personnel to design, but the designs should be sufficiently extensive when moving to the construction phase so that the site personnel can only focus on execution based on the plans.

Learning through the feedback of the production phase can be difficult, as it might be hard to verify the effect of a specific building solution on the success of the project. Because of this, false assumptions on the feasibility of a building solution can be made, as the solution itself could be functioning, but for example the installation work or procurement might be unsuccessful in the project that make the solution appear as unfeasible. Modules (I1, I3, I5, I7, I11) and Noppaparveke (I1, I2, I9, I8) are considered as such solutions, as many of the interviewees mentioned them as solutions which itself are probably good but have still problems in correct implementation.

5.2.4 Analysis of direct and indirect costs

As described in chapter 2.2, majority of the project costs are defined in the design phase but realized only in the construction phase (Kankainen & Junnonen 2015). Therefore, the follow-up of project costs can be challenging from the design management’s point of
view. Currently, also cost learning of design management has been through the feedback of the production phase (I1, I2, I9, I11) but the cost knowledge has not been seen as sufficiently transparent in order to gain sufficient information on the cost success of specific solutions (I12).

Most of the interviewees consider the analysis of the indirect costs of building solutions to be insufficient at the moment (I1, I2, I4, I9, I5, I7, I10, I11, I8, I12). As also the evaluation of the dependencies and constraints, so is the evaluation of the direct and indirect costs of building solutions dependent on the Design manager’s willingness and efforts (I3, I5, I12). The Design manager might rely on their own expertise or when necessary, consult the production and/or accounting teams (I4, I8, I12). There are no actual tools to support this evaluation, but each Design manager might do their own comparisons using programs such as Microsoft Excel (I1, I3, I11, I12) or look up the cost information from past projects (I2, I3, I7, I10, I11, I8, I12).

The cost accounting of the project in the design phase does not take into account the indirect costs of building solutions but is based solely on the direct costs. From the different alternatives, generally the one with the lowest technical cost is chosen (I1, I5, I7, I10, I8, I12). This disregarding of the indirect costs has led to choosing of building solutions, which by their technical price seemed the cheapest alternative but have generated indirect costs in the construction phase because of some other solutions that have had to be chosen to support the first one. (I1, I3, I4, I9, I10) By the feedback from the production phase, some of these mistakes have been detected, and the overall effect of the totality is better considered so that the determining aspects include also the quality, the easiness of the execution of the solution, the shipment costs, life cycle costs, guarantee costs and the effect on the schedule of the project, and not just the direct cost (I4, I5, I6, I11). Determining the indirect costs of a building solution beforehand is extremely difficult, as for example it might be impossible to know if a certain thing takes two or four times longer to complete (I3, I5, I7). Therefore, estimation of the indirect cost can be considered more of a matter of opinion than be based on facts (I3), at least until there is sufficient realization knowledge.

The challenge of design management in general has been cost awareness, as the designs are furthered quite far before conducting first cost estimates and realizing that the chosen solutions are too expensive (I4, I8). There are a lot of small things that are just a little bit more expensive and little bit harder to execute (I4), that accumulates into significant cost overruns of the project. Therefore, a strong leadership of the designers is important. (I1, I9, I7) The challenge also is that knowing how to identify these things is tacit knowledge based on experience, that is not commonly available (I5, I7, I12).

5.3 Existing building solution selection process at Fira’s residential construction unit and validation of findings

In order to broaden the perception of the design process and to validate the findings of the interviews, participation observation in design meetings as well as evaluation of existing data was used. The selected project was a residential construction project in Helsinki, where three separate buildings are constructed in three phases. This project, called Kellulaudankuja, was selected as it included several active phases from design to construction at the time of the research, so that the different phases of the process could be observed simultaneously. The project phases ongoing at the time of the research are presented in Figure 18. The project represented a fairly typical residential construction pro-
ject, with typical challenges experienced in the context of Fira as well as the whole residential construction sector in the capital region of Finland. This further supported the selection of the project, as the results could be generalized to apply in Fira’s projects as well as in other similar projects in other companies.

Figure 18 Ongoing phases of Keinulaudankuja project at the time of the research.

As the project comprised all three buildings, the project planning was done jointly to all three buildings in the beginning of the project. Therefore, the decisions regarding some of the building solutions were already made in that phase. These selections included the visible appearance of the buildings that were mostly dictated by the regulatory measures. Participant observation was conducted by attending the design meetings of both Building 2 and Building 3. The building site of Building 1 was visited to observe the execution of the plans.

All the material from the start of the project was reviewed, and a specific building solution was selected to examine the decision-making process leading to the selection of the solution. The balconies were selected, as they are a distinct building solution that still has various effects on the rest of the building and the building solution decisions. The Verstas minutes as well as other design notes of the project were studied to find out how different balcony options were studied and what the selection was based on. The findings of the evaluation are presented in Figure 19.
Reference plan 11/2016
Balconies are placed on both the street side as well as the inner court side of the buildings
The balconies can be recessed, Juliet or protruded type

Building specification 3/2017
All apartments must be equipped with a balcony (minimum 2 m²)
The balconies are mainly done with Fira's white concrete modular balconies (Noppararveke). Some of the balconies are executed as recessed balconies and some as Juliet balconies.

Verstas minute 3/2017
Facade plans containing Noppararveke balconies and recessed balconies
9 different layouts for apartements, from which 8 has a Noppararveke balcony and 1 a recessed balcony.

Project plan 4/2017
The balconies are either prefabricated Noppararveke balconies or recessed balconies

Figure 19 The selection process of balconies in Keinulaudankuja project.

The process started from the reference plan, where the constraints of the city plan were considered. At this point, there was no restrictions to the type of the balcony, but they were defined to be either of the three types. The demand that balconies must be placed on the street side poses some restrictions, as the balconies cannot be supported from the ground on that side of the building. The next documentation on the balconies is in the building specification document, where the types of balconies are selected. Even though the requirement of a minimum of two square meter balconies is realized, the possibility to use Juliet balconies in some apartments is still investigated. Because there is no documentation leading to the selection, it is not clear why Noppararveke balconies are selected as the main type and why some apartments would still be equipped with a recessed and Juliet balcony. In the project development Verstas phase, the apartment layouts and façade plans are produced, and the amount of Noppararveke balconies and recessed balconies are set. In the Verstas minutes, the different apartment layouts including the type and position of the balcony are explored. One of the layouts is modified so that the recessed balcony is replaced with a Noppararveke balcony, resulting in 8 apartment layouts with Noppararveke and 1 layout with a recessed balcony in all three buildings. The Juliet balconies are not included in the plans, which might indicate that applying this balcony type was not possible due to the minimum requirement on the size of the balcony. The final
project plan states that Nopparparveke balconies and recessed balconies are used, which makes the selection final.

The findings of the evaluation of the Big Room minutes and notes supports the findings of the interviews, where Nopparparveke balconies were mentioned as a standardized solution that is strive to be used in residential construction projects. Although there was no documentation on the factors that led to the choice of balcony type, it seemed that Nopparparveke balconies were used when possible and other types of balconies adopted to the plans when needed. As also discovered in the interviews, the revision of different alternatives was not done in the Big Rooms and it was not documented or commonly presented. Based on the interviews it could be concluded that exploration of the alternatives was done in unformal situations or solely by the Verstas manager, and the formal decision was made and documented in the Big Room or other meeting based on the suggestion of the Verstas manager. As the selection process was completely undocumented and possible comparisons made were not presented in the minutes and notes, the selection cannot be utilized in future projects, but the effects and justifications need to be started from scratch.

In addition, the costs relating to the balconies were reviewed to find out the extent of indirect costs being considered in the selection as well as possible cost overruns that would have resulted from insufficient annotation of costs. The costs were reviewed together with the Site engineer of the project, so that all factors relating to the work yet to be done as well as extra work could be noted. Cost revision focused only on Building 1, as at the time of the research it was the only one under construction thus causing accumulation of costs. Building 1 included 79 balconies in total, that all were Nopparparveke balconies. The costs included in the original cost estimate and the actualized sources of costs are presented in Table 3.

Even though all the balconies in Building 1 were installed at the time of the research, all the costs had not yet been accounted for. There was still ongoing work done relating to framing of the window sills, seaming and coping. The work relating to the window sills was done as timework and thus accounted under this category. Coping, timework and hardware store purchases were not originally accounted to be a part of the costs of the balcony, but as general categories including several different building solutions. Therefore, these cost categories held indirect costs related to the balconies, that were not accounted for in the original cost estimates. There were also some costs actualized that were directly relating to the balconies, but not accounted for in the original estimates. These costs, including costs for worktime protection, heating and drying of the balcony casts as well as steel parts needed to attach the balcony elements to the wall elements of the buildings were not accounted in the original cost estimates. The costs accounted originally as thermal insulation and waterproofing of the balcony jambs were split differently in the actualized cost accounts, where the costs relating to thermal insulation were considered inferior and the waterproofing costs were split under coping and installation costs. In addition, the Site engineer pointed out that the balconies combined with shuttering slabs had resulted in massive casts that had required extensive drying needs. The costs resulted from drying these casts were though accounted under the general drying of the whole building. As a result, as without this solution combination the drying needs would have been much lesser, the overall drying costs became much greater than anticipated. This was also affected by the season, as the building phase was ongoing during winter time, which in turn increased the need for heating and drying of the casts and the building.
Table 3 Cost accounting for balconies in Keinulaudankuja project.

<table>
<thead>
<tr>
<th></th>
<th>Original cost estimate</th>
<th>Actualized costs</th>
</tr>
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<tbody>
<tr>
<td><strong>Balcony elements</strong></td>
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<td>x</td>
</tr>
<tr>
<td>Glazing and handrails</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Installation of elements</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Finishing of concrete surfaces</td>
<td>x</td>
<td>Accounted in the denomination of the outer walls</td>
</tr>
<tr>
<td>Acoustic panels</td>
<td>x</td>
<td>Not needed in the project</td>
</tr>
<tr>
<td>Elastic seaming between balcony and outer wall</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Thermal insulation and waterproofing of balcony jambs</td>
<td>x</td>
<td>Partly accounted in installation and coping costs, thermal insulation costs considered inferior</td>
</tr>
<tr>
<td>Protection, heating and dehydration</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Steel parts of frame</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Coping</td>
<td>General category including many building solutions</td>
<td>x</td>
</tr>
<tr>
<td>Timework</td>
<td>General category including many building solutions</td>
<td>x</td>
</tr>
<tr>
<td>Hardware store purchases</td>
<td>General category including many building solutions</td>
<td>x</td>
</tr>
</tbody>
</table>

The original cost accounting did not include any indirect cost considerations, but the most feasible ways of execution were thought out onsite. These considerations included costs relating to safety, drying, protection of materials and working order that affects the need for cranes and workers onsite. The different approaches in the cost accounting also seemed to produce confusion in the actualized costs, as some costs included in the original estimates of the solution were accounted under other building solutions and vice versa. The portion of a specific building solution in a cost category was also not always clear, as for example grouting that was part of the element installation cost. Because of this, evaluating the total costs of a specific solution was proven to be extremely difficult.
5.4 Evaluation and discussion of the review

In this chapter the collected material is analyzed together with the findings of the literature review and development suggestions are presented. Based on the analysis, the suggestion is formulated, and the tentative process is further developed and presented in chapter 6.

Process and practices

The lack of a working process in the design phase was identified as a problem in both literature as well as interviews. As Aapaoja & Haapasalo (2014) pointed out, in development of construction design, the process needs to be developed first, so that it supports the usage of standardized products and modular building solutions that in turn promote adaptation of lean culture and waste reduction. As Fira has lately focused on formulation process and task descriptions, it could be concluded that the first steps towards the right direction have already been taken. The selection process of building solutions is thought yet undescribed, thus still resulting in variation and individually developed ways of acting between the projects. This lack of a working process was also identified in literature as a major challenge of design management (Koskela 2000, Daniel et al. 2017). A formulation on the selection process of building solutions was obtained by Haymaker et al. (2018), where the process was found to consists of a problem formulation, alternative generation, impact analysis and value assessment. Both in literature as well as in Fira, most of the problems in the process were obtained to be dealing with impact analysis and value assessment, whereas problem formulation and alternative generation was not mentioned at all by the interviewees.

The selection process of building solutions should be modeled in Fira, so that a common way of acting could be established that promotes the use of certain solutions that are wished to be advanced and that learning in those solutions would take place. As though concluded by Rosas (2013), development of the selection process through learning from the production phase is hard, as defining the extent a certain building solution have affected the outcome is often impossible. Also, the various project delivery methods and temporary project organizations make learning challenging (Ballard & Howell 1998, Rosas 2013). This has also been seen at Fira, where repetitive mistakes have resulted from fragmented organizations where learning has occurred mostly on a personal level.

The current selection process in Fira was obtained to be totally dependent on the person, with no distinct tools used. Although in literature many tools were found to exist, none of them have gained a solid foothold in the industry, thus still resulting in various processes. The current design process practice in the industry was obtained to be consisting of many phases, where the level of detail is constantly added building on past decisions in the process. Therefore, the beginning of the design process can be concluded as the most critical (Knotten et al. 2014). In Fira, this has not been sufficiently identified but the decisions made in early stages of the project have in some cases resulted in unfavorable solution combinations later in the project, where influencing possibilities have been limited. This additive level of detail being the current practice in the industry has also been hard to combine with modular building solutions, that should be taken as a perquisite for other solutions, rather than adapting to fit to existing plans. (Aapaoja & Haapasalo 2002, Gibb & Isack 2003) This also amplifies the importance of early design involvement and thorough impact analysis, as all issues need to be solved before moving to the construction phase (Peltokorpi et al. 2018b).
In literature, the still often fragmented and cost-driven selection process (Pan et al. 2012) is often strived to be simplified with the use of modular building solutions. As traditionally buildings are divided according to the different trades (Bertelsen 2005), modular solutions combine the expertise of these trades in a single module with standardized interfaces, making the design work and product selection easier to manage. Also in Fira, modular building solutions have been introduced as an attempt to simplify the design as well as the construction onsite but so far the fundamental justification of their usage has been lacking.

Process development should focus on improving impact analysis and value assessment phases of the selection process, as most of the problems were considered to be relating to them. In Fira some comparisons of building solutions had been made, but mostly these were done for one’s personal use and thus not benefiting other decision-makers or projects. Hence documentation of the whole process should be improved to support learning and prevent reoccurring of same mistakes. Many aspects imposing indirect costs were only thought out after the selection of the building solution in the construction phase onsite, where the ability to influence these costs were limited. Therefore, also the indirect costs should be considered before the selection of a building solution or a solution combination that would increase cost awareness and cost influencing possibilities.

**Standardized solutions**

The importance of standardization both in building solutions as well as processes was evident in both literature and interviews. In literature, standardization of the design process was seen to enable prefabrication and modularization, that in turn is believed to bring benefits in the form of better productivity and cost savings. Bertelsen (2005) also identified the building to be comprised of visible and hidden building solutions, from which the visible ones are meaningful to the customer and should be convertible, whereas the hidden solutions should be standardized as much as possible. The interviewees believed that standardization of the selection process would decrease unwanted variation in the projects and provide better opportunities for the use of standardized building solutions. Furthermore, the interviewees considered that the building solutions primarily offered to the customer should be selected and documented clearly, so that knowledge on them could be utilized from project to project. Although some solutions were identified as standardized solutions by the interviewees and their usage was found to be promoted in the material evaluation, a collection of the standardized solutions of a company, often referred to as a solution library, was seen to be lacking in Fira by most of the interviewees. In literature, solution libraries were seen as a way to promote the use of standardized solutions in a company (Eastman et al. 2012), but the often cost-oriented nature to be insufficient as the bare selection criterion.

In order to fully realize the benefits of standardization, a company should focus on both process as well as product standardization (Aapaaja & Haapasalo 2014). On top of the process standardization described above, Fira would benefit from development of the solution library as well as selecting certain building solutions that are repetitively strived to be used in residential construction projects. According to literature, standardization should be ideally applied to the interfaces of products, striving for as sectional component interfaces as possible thus mitigating design work. (Aapaaja & Haapasalo, Bertelsen 2005) As offering a fully standardized building is not possible due to regulatory provisions and site conditions among other things, also a way of selecting a previously unused solution should be thought out. Fira is also highly customer and service-oriented and offering only certain options would not be supporting this ideology. Therefore, the selection
process of building solutions should utilize existing solutions as much as possible but allow also adaptation of an unused or undocumented building solution.

**Decision making**

In literature, the whole construction design process is considered to be a decision-making process (Haymaker et al. 2018), where value-based methods should be favored to reach the best project outcome (Chan & Chan 2014, Arroyo et al. 2018). Decision-making is closely connected to the selection of building solutions, as the decisions on which solutions to be used in the building furthers the design process and shifts it to more of a sequential logic making it easier to manage and eventually results in ready designs (Knotten et al. 2014). In Fira, the current exploration of alternatives was dependent on the person leading the design, with no clear process. In literature, the problem with the adequate amount of exploration of alternatives was also identified. As value-creation, contradictory to Lean principles, is seen to derive from variation (Bølviken et al. 2010), several alternatives should be considered before reaching a decision. On the other hand, delaying decision-making might result in hindering the efficiency of the process (Singer et al. 2009) and the budgets and deadlines preventing extensive exploration altogether (Haymaker et al. 2018). Even though there are some methods developed to aid in this process, these are often too specific, focusing in the selection of a specific building system and the process is often nonexistent (Blismas et al. 2006).

Some informants in the interviews pointed out that the decision-making practices in Fira are often lacking, as the decision maker and moment are always not clear. Decision-making is hesitated because the impacts of the decisions are not understood and there is a fear that the decisions made will affect the future process in an unfavorable way, for example with difficult or costly solution combinations. The variety of consideration of different aspects is dependent on the person and their experience in the field. There is no clear decision-making process, but the person leading the design decides how different building solution alternatives are considered, which project parties are involved and what aspects are considered. Also in literature, the decision-making was often found to be solely based on opinions and past experiences (Blismas et al. 2006) and direct cost comparisons (Vihinen 2017). As in Fira, in literature the design work was also found to be often done with defective information from the production side (ICG Guideline 2015). In Fira, the decision-making often occurs in informal and unrecorded surroundings with no clear documentation, thus resulting in decision makers not being able to base their decisions on past projects, but the considerations must be made all over again. This was also noted in the Big Room minutes and notes, where the decisions were documented, but the motives behind the decisions were not. Also Koskela (2000) identified this type of uniqueness to be typical for the design process leading to generation of waste and repetition of same mistakes.

In the interviews, the most often mentioned aspects affecting the selection of building solutions (Table 2) support the findings of Chan & Chan (2004), where cost, schedule and quality accuracy where the most typical project success factors. The aspects that Fira has been struggling with can be seen to be emphasized within the answers of the interviewees. Moisture control, easiness of the execution and expected guarantee costs are all frequently mentioned. Also, as Fira contracts for customers, the desires of the customer are seen to be an important selection criterion. From the answers of the interviewees, certain criteria can be seen to recur within the groups. The production group mentioned criteria related to the production phase such as constructability and the effect on the schedule. The design management being responsible for the determination of the project.
costs, most often mentioned cost as a selection criterion. In addition, besides schedule
effects, the quality / warranty group mentioned moisture control as the selection criterion.
From this can be concluded that the professionals often focus mostly on their own fields
in the selection criteria of building solutions, not being able to consider the full situation.
This is only natural because each designer is an expert in their own field only, but as the
demands would require concurrent consideration of several subsystems (Koskela 2000),
new methods to combine the expertise of different professionals should be developed.

The problems in the decision-making process were especially evident in the selection of
modular building solutions. As the current decisions are made based on opinions and ex-
perience (Blismas et al. 2006) and the benefits of the modular solutions are in the value
aspects and cost reductions by indirect savings, the potential of them has been hard to
perceive by traditional evaluation methods. Also in Fira, the current decision-making on
the use of modular building solutions was based on strategy and assumptions, rather than
actual data. Both in Fira as well as in literature, attitudinal issues and practical guidance
were also identified as barriers hindering the uptake of modular solutions (Gosling et al.
2016). As the degree of modularization in Finland is still relatively low (Kotilainen 2013),
also the the lack of compatible systems hinders uptake of modular solutions as modifying
them so that they fit with rest of the building solutions is only perceived to add cost and
complexity, rather than eliminating it.

The decision-making process on selection of building solutions should be modeled to
ensure timely and informative decisions that in turn would promote learning from project
to project. Documentation of the selections should be improved, so that it would be clear
why certain building solutions have been selected in projects and what aspects the deci-
sions are based on. The circumstances can vary between projects, and a building solution
that has been profitable in one project, may not be so in another project. Therefore, the
selection criteria should be clearly presented, and future decision-making based on as-
sessing the similarities and differences in the projects. The selections should be value
based rather than solely cost-oriented and involve the expert opinions from different pro-
ject parties. The selection process could benefit from adaptation of a value-based selec-
tion tool, such as CBA. As also found in literature, the combination of a visual tool such
as argument trees to a MCDM method was seen to aid in finding the possible scenarios
and their documentation (Cooke et al. 2008).

**Dependencies and constraints**

There is little consideration on the dependencies and constraints of building solutions in
literature. The impact analysis is often restricted to stability and constructability issues
and clash detection, performed by designers with the help of parametric modeling tools
(Eastman et al. 2012). The dependencies between the design tasks have been identified
(Mujumdar & Maheswari 2018) but extensive analysis on the dependencies between the
different solutions or solution combinations does not exist. In literature as well as in the
interviews, modularization and standardization were suggested as a means to reduce the
dependencies and constraints between the different building solutions (Tee et al. 2019).
At its best, the modular product architecture with standardized interfaces meets these re-
quirements, as the more sectional the component interfaces are, the more dependencies
between the components can be reduced (Aapaoja & Haapasalo 2014, Bertelsen 2005).
As the modular systems though often hold several different product architectures with
various interfaces (Voordijk et al. 2006), some dependencies might be reduced but also
others created, still requiring impact analysis of components.
The current analysis of dependencies and constraints of building solutions performed in Fira was believed to be insufficient and dependent on the person leading the design. The unfavorable solution combinations were seen to be resulting from scarce experience of the company in residential construction, the inadequate process in impact analysis in the design phase as well as new and unfamiliar building solutions. The designs had usually also been furthered quite far without realizing the problems resulting from dependencies and constraints. In literature, the need for an early involvement in the design process especially regarding modular building solutions has been identified among others by Aapaaja & Haapasalo (2014) and Peltokorpi et al. (2018b). Therefore, in the consideration of dependencies and constraints, a more front-end weighted manner should be introduced.

In Fira, the success of different design solutions as well as solution combinations has mainly been realized by the feedback of the production phase. The difficulty of this method has though been noted by both the interviewees as well as in literature. Rosas (2013) noted that the mistakes in the design process are extremely hard to identify, as it is impossible to know to what extent a failure has resulted from a poor design solution. The interviewees also pointed out that the deviations in the project outcome can result not only from a poor design solution but also from poor execution, poor procurement or un-anticipated circumstances in the building site among other things. A good design was also obtained to be hard to define, because of the many project parties and their different goals (Whyte et al. 2003).

In literature, although no real tools to perform extensive analysis on dependencies and constraints were found, different types of hierarchies were obtained to have proven effective in representing them. Also, to support front-end weighted design, a method to analyze the impacts of the building solutions already in the design phase should be developed. As for documentation on the selection criteria of the solutions, also information on the dependencies and constraints should be well documented in order to ensure effective learning and visualization of tacit knowledge. The use of modular building solutions should be promoted, but as the degree of modularization is still quite low in multi-story building in Finland, impact analysis is still needed. The level of standardization within the building solutions should also be increased so that existing information and analysis on the building solutions could be utilized as much as possible.

**Direct and indirect costs**

The past LDM research has mainly focused on flow management, collaboration and waste reduction where many tools and methods have been developed, but the value managing and enhancing aspects have been disregarded so far (Jørgensen 2006), resulting in insufficient methods in direct and indirect cost management. The analysis of direct and indirect costs of building solutions has also been one of the major challenges in Fira’s design management. The new process descriptions are though perceived to improve the cost awareness in the projects by the interviewees, hopefully leading to less cost surprises and better cost knowledge. Even though this cost control ensures that the estimated project costs do not exceed the budget of the project, it does not promote identification or learning of the indirect costs of building solutions, as they are still reported mainly under operating and joint costs during production phase as could be seen from the cost accounting for balconies where almost half of the cost categories were not considered in the original cost estimates. This has also been noted in literature by Blimas et al. (2006) who identified this type of cost reporting to be amplifying the unawareness of the true origin of costs.
Some of the interviewees desired methods that would promote a more transparent cost knowledge throughout the project, and thus enable more informative choices to be made in the design phase. In literature as well as based on the interviews, the selection of building solutions is often mostly based on the direct costs of the solution (Vihinen 2017). Currently the interviewees mostly regarded that the evaluation of the indirect costs is extremely difficult because of the variance and randomness in them. In literature, some methods have been developed to perform a more value-based selection of building solutions (Pan et al. 2012), but no such methods have been widely used in Fira. In literature, the slow uptake of modular solutions has been identified to be resulting from poor consideration of the indirect costs (Blismas et al. 2006). This was also observed in the interviews, where some informants pointed out that modular solutions were used in the company as they were believed to bring savings, but no real evidence had been presented.

The selection process of building solutions should involve a consideration of both direct and indirect costs, so that cost overruns and surprises could be prevented as much as possible. Prefabricated building solutions also generally hold more direct costs, resulting often in a higher technical cost than the corresponding onsite built solution, but also hold more indirect cost savings that are currently unable to be shown (Blismas et al. 2006, Smith 2010). Indirect cost knowledge should therefore be more accurately documented so that it could be utilized when assessing the feasibility of building solutions in the design phase. The true advantage of building solutions including modular solutions should be presented, so that selections based on assumptions could be ended both in literature as well as in Fira.

5.4.1 Summary

Fira was obtained to be struggling with the same issues identified in literature, concerning the lacking impact analysis, inability to justify the selected building solutions and adaptation of modular solutions due to the contradictions to the current practices of the industry. The design process in Fira was identified to have the following development needs based on the interviews, material evaluation and the literature review:

1. The selection process of building solutions should be modeled
2. A method to analyze the impacts of building solutions should be developed
3. The selections of building solutions should be based on analysis of the true situation rather than assumptions and experience
4. Documentation should be improved.

The development suggestions in the building solution selection process are presented in Figure 20, where the selection process is formulated according to the description by Haymaker et al. (2018). As the problem formulation was not obtained to contain problems it should be carried on as before. Alternative generation should focus more on utilization of standardized solutions, and the familiarity of the solutions should be considered as a promotive factor. Impact analysis was the most disregarded phase in the building solution selection process both in literature and in the company based on material collection. No tools were found to support this phase, that was currently mostly based on experience and personal efforts of the design leader. Although the design process should not be unnecessarily delayed with impact analysis on known solutions, basing selections on assumptions or possibly outdated experiences should be avoided. Thus, impact analysis should be carried out when considering new or previously undocumented building solutions, so that these documentations could then be further utilized in following projects. Impact analysis
should include evaluation of the dependencies and constraints of the building solution, as well as strive to present both direct and indirect costs associated with the solution and the resulting solution combinations. Finally, the selection of the building solution should be based on value rather than only cost. These value-based selection methods have been explored in literature somewhat extensively, and based on the literature review, adaptation of CBA in this phase of the selection process is suggested.

Based on the findings, a tool to support impact analysis should be developed. As concluded in the literature review, hierarchy models have proven efficient in presenting the type of tacit knowledge related to dependencies and constraints. The tool should also support value assessment and the usage of CBA, so that it would not be disconnected from the selection process but rather supporting it. This could be executed by highlighting the advantages with a distinct color, that would further visualize the impacts of different options. Based on these criteria an outline for the tool is presented in Figure 21. The tool and the process related to it is further developed in the next chapter, and the tentative process is presented.
6 Suggestion formulation

In the previous chapter, the development needs and suggestions in the building solution selection process were summarized and the outline for the impact analysis tool presented. In this chapter, the suggestion of a selection process including the impact analysis tool is further developed and adapted for the needs of the residential construction unit of Fira, resulting in the tentative process. The first part of the suggestion formulation is focused in developing the impact analysis tool, after which the selection process utilizing the tool is presented. The used research approach and material collection methods are first introduced, after which the tentative process is composed.

6.1 Research approach

The main research approach used in the development of the impact analysis tool is a workshop style approach, where the researcher works together with the professionals of the company to solve the problem at hand. Ørngreen and Levinsen (2017) define workshop as an arrangement whereby a group of people learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-specific issue. This intensive and innovative method that supports co-operative innovation is not only fully supporting the nature of a DSR method but also an effective way to solve problems. As the goal of this phase of the research is to formulate the suggestion for the artifact, a method that is focused on creating and not only acquiring knowledge such as an interview, is justified.

The impact analysis tool was formulated in parts involving different experts from the company, until no new information was presented. The development of the tool was done in a project that is already in the construction phase in a kind of backward nature, which means that instead of trying to formulate aspects that should be considered in the design phase and in the selection of the building solutions, the aspects that should have been considered are found. This method brings out the true needs for the selection process, so that waste from too extensive or too concise considerations could be avoided. Also, as especially the indirect costs and effects of solution combinations are clearly seen only in the construction phase, formulating the process to consider these issues based on evidence rather than speculation is feasible. Utilizing an existing situation in the development is also supporting the use of the workshop approach, as the true operation of people in specific circumstances is often surfaced only in the situation through their behavior (Argyris & Schön 1996).

6.2 Selection of solution to be investigated

The development process of the impact analysis was decided to be formulated with the help of an actual building solution. As the research is focused on modular solutions this defined the selection of the solution. Formulating the impact analysis based on a modular solution is justifiable also because they often hold more indirect cost effects than traditional onsite produced solutions, thus requiring more consideration to be justified. Even though currently modular building solutions often have more expensive direct costs than corresponding non-modular solutions their usage is still furthered, as the indirect effects are believed to hold cost savings. These cost savings have though not been able to be proven, as the current impact analyses are insufficient leading to selection of building solutions based on direct costs rather than value (Blismas et al. 2006). The indirect effects
should be made visible, so that the selections could be based on facts rather than assumptions and the right building solutions for each project found.

Fira has developed a few modular building solutions of its own, that have been developed to increase the productivity of the residential construction projects. The solutions developed or jointly developed by Fira and other companies include Noppararveke balcony, Modules bathroom element and Luja-superlaatta baffle plate. Fira though struggles with the same difficulties as were found in literature, as the solutions are believed to bring savings through indirect effects, but the cost efficiency has failed to be proven. Because of this, selection of these solutions is currently based rather on business strategy and assumptions rather than actual data. As Fira pursues to use these modular solutions, there is a need to identify the impacts and challenges of the solutions already in the design phase. Several interviewees mentioned Noppararveke balconies and Modules bathroom elements as solutions that should be further investigated in order be able to recognize and consider their impacts correctly in the design phase.

In addition to the needs for further analysis from Fira, the researcher was already familiar with balcony solutions based on the material collection, thus supporting the selection of Noppararveke balconies as the building solution used to formulate the tentative process. The balconies were also a central part of the Keinulaudankuja project under review, where also the to-be constructed buildings have Noppararveke balconies.

6.2.1 Noppararveke balcony

Noppararveke (in English cube balcony) is a prefabricated modular balcony, that is cast as a single piece from white concrete. Structurally, Noppararveke balconies are equivalent to a protruded balcony and can be freely placed on the façade of the building. Noppararveke balconies (Picture 1) are jointly developed by Fira and Parma and produced by Parma. The balconies were originally developed for a residential construction project of Fira, where steel balconies were considered too expensive and not suitable in their visual appearance. Since then, Noppararveke balconies have been used in three residential construction projects by Fira. The balconies are also begun to be sold to other construction companies, which further increases the need for accurate information on possible cost savings. Currently, Noppararveke balconies are believed to bring cost savings in the installation speed and easiness of design, as the structural solutions are readily available, and placement of the balconies can be done freely without restricting the layouts of spaces.

Some cost comparisons between Noppararveke balconies and other balcony types have been done at Fira. One of the comparisons found in the sales material of Noppararveke balconies, indicate that the balcony type is the second most cost-efficient alternative after stacked balconies with jamb elements, when pillar balconies, Schöck balconies, hung balconies and recessed balconies were also included in the comparison. The costs included design costs, wall structures, element installations, doors and windows (related to the balcony) and glazing and railing of the balconies.
6.3 Material collection and analysis

The formulation of the tool was done in phases, in dyadic workshops with different experts form the company, until no new information was presented. As for the selection of interviewees in material collection in chapter 5, expeditious sampling was also applied in the selection of examinees for the workshops. Experts were selected based on the information attained from the interviews on the involvement of certain groups in the design phase so that those believed to hold material on the subject of interest were involved.

The tentative process was formulated in four phases. The experts involved, and the focus of the workshops are presented in Table 4.

Table 4 Workshop examinees and focus.

<table>
<thead>
<tr>
<th>Group</th>
<th>Designation</th>
<th>ID</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Construction manager</td>
<td>I2</td>
<td>Structural dependencies, production perspective</td>
</tr>
<tr>
<td>Design management, solution development</td>
<td>Design manager</td>
<td>I9</td>
<td>Structural dependencies, design perspective</td>
</tr>
<tr>
<td>Accounting</td>
<td>Accounting manager</td>
<td>I1</td>
<td>Costs, design perspective</td>
</tr>
<tr>
<td>Production</td>
<td>Site engineer</td>
<td>I13</td>
<td>Costs, production perspective</td>
</tr>
</tbody>
</table>
The workshops were conducted by the researcher in March 2019. All the workshops were conducted face to face. The workshops and the formulation of the tool were conducted in Finnish, so that all information could be collected in the first language of the participants, thus avoiding issues caused by a language barrier. The hierarchy model was created with an open source browser-based diagramming application called draw.io. The software was selected as it is easy and intuitive to use, it is free and available to everyone in the company and provides good export options on the created diagrams that supports documentation.

In the first workshop with the Construction manager, the hierarchy model for the Noppaparveke balcony was created. The hierarchy was concluded to include six first level headlines that are structural demands, installation, finishing, shipment and storage, design and quality / warranty. Under these six headlines can be categorized the affiliated building solutions and the requirements and effects of the building solution thus making them applicable to all cases and forming a template for the tool (Figure 22). The surfaced development needs of the building solution were gathered in a separate table next to the hierarchy.

![Diagram]

Figure 22 Template for impact analysis tool.

In formulation of the hierarchy, the following questions were used to aid the thinking process:

- What are the requirements for the application of the building solution?
- What are the effects of the building solution?
- What building solutions are affiliated to the building solution under review?
  - What are the effects of the solution combinations?
In the following workshops, the formulated hierarchy model was supplemented, until no new information was emerged. In the first two workshops, the main focus was on the structural dependencies, that included the affiliated building solutions and the required work tasks in combining them as well as the effects of the formed solution combinations. The following two workshops focused on determining costs for the identified parts in the hierarchy. In all the workshops, advantages and red flags among the identified components of the hierarchy were also identified and marked in the hierarchy with distinct colors. The advantages were highlighted in green, to further visualize the selections with advantages and thus support CBA. Red flags were represented in red, and they included aspects that need to be solved before using the solution or aspects greatly affecting the usage, and thus requiring a detailed plan of execution already in the design phase. The red flags are thus not preventing the usage of a specific solution or solution combination, but rather represent the need for extra consideration in the implementation strategy. The obtained hierarchy of Noppaparveke balcony is presented in appendix 3.

In the workshops, the hierarchy model was proven to be an effective way to visualize the dependencies and constraints related to the building solution, thus successfully supporting the selection process. The examinees found the hierarchy easy to understand without further explanation, thus making its adaptation in the selection process easy. Although costs could not be identified to all components in the model, gathering the information and alternatives visually as well as presenting advantages and red flags were seen to support the selection in an adequate amount. The hierarchy model could also be completed easily whenever new information is obtained. In the next chapter, the tentative process that utilizes the developed impact analysis tool is presented.

6.4 Tentative process

The tentative process in selection of building solutions including impact analysis is presented in Figure 23. The process outline is already in use at Fira in the form of a solution workshop developed by Lehtovaara (2018), where the identified problems in the production phase of a project can be solved with a 5-why analysis. The process model has therefore already proven to be effective and suitable in the context of the residential construction unit of Fira. The process outline is modified to serve the needs of selection of building solutions, but the main process is kept the same.

Figure 23 The tentative process.
Implementation

As selection of building solutions takes places in several stages in the design process, the process model might be utilized in different stages of the design process. The Design manager or Project engineer can decide to execute the selection process, if the plans are obtained to hold unfamiliar or previously undocumented solutions, which require greater impact analysis. As there are also specific points in the design process formulation where the plans are reviewed, these points are the minimum requirement for the selection of solutions to review. Therefore, the selection process is justified to be included in the gate between options appraisals and concept design (gate 2) and again in the gate between concept design and detailed design (gate 4). The owner of the process is the Head of design of the residential construction unit, who oversees development of building solutions and their selection.

Alternative generation

As identified in the literature review, according to Haymaker et al. (2018) the selection process involves stakeholders, gatekeepers, designers and decision-makers. In the tentative process (Figure 23), the goals and preferences of the stakeholders that could be seen to consists of the customer and the contractor are managed by the Design manager or Project engineer, who considers them already in the alternative generation. The restrictions of the gatekeepers that can be seen to consists of the authorities are also taken into account in the alternative generation by the Design manager or Project engineer as there is no use to further options that either do not fulfil the requirements of the customer or contractor or by the authorities. The Design manager or Project engineer selects 1-3 building solutions that fulfil the goals and restrictions, that are unfamiliar to them and from which no previous impact analysis documentation is available. Together with the Site engineer and/or Construction manager, the Design manager or Project engineer prepares the hierarchies of the solutions utilizing the template (Figure 22) and the questions formulated in chapter 6.3.

Impact analysis

Impact analysis is performed in a workshop type meeting, lasting about an hour. According to Westerlund (2007), a workshop should consist of three parts that are introduction and open discussion, creation and analysis and thirdly planning of the follow-up measures and reflection. This way the participants have a clear picture on the context of the problem before the analysis, as well as of the follow-up measures and responsibilities so that actual development can take place. The workshop is structured to comprise of three parts, according to Westerlund (2007) and the evaluation of the workshop process by Lehtovaara (2018):

*Introduction: 20 minutes*

- Introduction on the structure and goals of the workshop
- Presenting the situation and the hierarchy model

*Creation: 20 minutes*

- Open discussion
- Supplementing the hierarchy model, impact analysis with advantages and red flags
- Formulation of follow-up measures
Follow-up measures and reflection: 20 minutes

- Defining the responsibilities and deadlines for follow-up measures
- Reflection on the process and results

The participants of the workshop are based on the participants involved in the creation of the impact analysis tool and the findings of the process model by Lehtovaara (2018). The participants should involve only the necessary parties and people that are believed to hold the broadest amount of information on the subject. The Design manager or Project engineer is responsible for setting motion to the process and should involve the necessary parties based on one’s own experience or by asking around to find the appropriate participants. The participants illustrated in the tentative process (Figure 23) are thus not definite but should be considered case by case. According to Haymaker et al. (2018) the key parties in the impact analysis are the designers. In addition to the traditionally considered designers, the participants of the workshop are pursued to hold also cost and production expertise from various viewpoints, as these are also fields inflicting impacts on to the solution and thus affecting the final outcome. In order to ensure a compact and productive workshop, a facilitator should also be selected. The facilitator can be either one of the identified parties or outside them such as the Head of design, but should possess adequate social and technical skills, keeping the impact analysis focused on likely options where the dependencies and constraints are posed by the solutions, not people.

Documentation and value assessment

Based on the follow-up measures and responsibilities, the developed hierarchy is documented and stored in the solution library of the company. According to Haymaker et al. (2018) the value assessment is done by the decision maker that could be the Design manager or in some cases the customer. This can be effectively carried out once the impacts of the solution are carefully identified providing adequate knowledge to reach a decision. In Fira, the Design manager is in charge of the designs, thus being the natural decision-maker in the process. Based on the developed hierarchy, the Design manager makes the selection of the solution combination based on advantages utilizing CBA. The Design manager or Head of design is responsible for the development needs and their furthering arisen in the process.

In this chapter the tentative process including the impact analysis tool is presented that is the tentative design for the artifact in the DSR process. The formulation of the tentative process was based on the literature review in chapters 2, 3 and 4 that was further focused and deepened in chapter 5 with semi-structured interviews, revision of documents and participant observation in the case company. In the next chapter the artifact is developed with testing and evaluating it in the context of the residential construction unit of Fira.
7 Development

In this chapter the artifact is tested and validated. Testing the model is an important part in the DSR process, where the functionality of the artifact is tested in practice, providing knowledge of future development needs and challenges with the model. Involving the end users of the process in the implementation provides knowledge on the model’s functionality in respect to the behavior of the participants in the actual situation as well as motivates the experts to adopt the process in their own working. Based on the findings the implemented process is developed and the final process is presented in chapter 7.4. The research approach used in the implementation of the model is presented in chapter 7.1 after which the building solution investigated is presented in chapter 7.2.

7.1 Research approach

The main research approach in the implementation of the model is unstructured participant observation. In this phase of the research, the participant observation was mainly active, which means that instead of only observing the situation without influencing the course of events the researcher actively participates in the development process. Anttila (2006) describes participation of the researcher in such situations to be comprised of two forms: on one hand as a participant in the process and on the other hand as an observer of the behavior of others. The advantage of observation is that it provides direct information on the behavior of an individual, group or unit. Hirsjärvi et al. (2014) also state that observation is well suited as a part of qualitative research, where the interactions of people and situations that are not easily predicted are studied. As the studied development areas of the process are dealing with the interactions of people in a situation that is new and thus not easily predictable, the use of observation in this phase of the research is justified.

Participant observation can be divided into structured and unstructured observation. Structured observation permits stronger generalizations and provide better reliability and validity but requires detailed parsing of the incidences beforehand. Unstructured observation is used when such formulation on the incidences cannot be made, thus requiring knowledge on the theory of the matter which provides certain expectations and allows formulation of conclusions. (Anttila 2006) Even though the process model is already been used in the company, adjusting it to serve in the particular purpose is new, which means that the incidences are not known beforehand and thus unstructured observation is used. As the researcher has gained a broad knowledge on the theory in the literature review and the evaluation of the current process, the expectations and hypotheses can be formed that serve as the basis for observation.

Observation methods have been criticized to be sensitive for error, as the researcher’s presence in the situation might disturb or even change the behavior of the participants. According to Hirsjärvi et al. (2014) this could be reduced with reoccurring situations, so that the participants get used to the researcher’s presence. As the researcher is familiar with most of the personnel due to several years of work experience in the company, the need to act differently is likely to be reduced. The observation methods should though be carefully planned because of the subjective nature and unpredictability of observation making. (Hirsjärvi et al. 2014) Observations should be as neutral as possible, without letting one’s own preconceptions affect the situation. Because the occurring incidences are not known beforehand, knowing what to observe and the significance of certain observations are always not known. The researcher should therefore not only observe the verbal contribution but also gestures, expressions and postures of the participants. (Anttila
2006) Hirsjärvi et al. (2014) also point out that all observations cannot be captured at the same time, but focus is drawn to certain things, leaving others unnoted. In addition, the emotional connection to the situation might disrupt the objectivity of the analysis. (Hirsjärvi et al. 2014)

The secondary research approach is a workshop style approach, that was used to test the tentative process. The participants were selected among the interviewees from the suggestion phase. Due to some personnel changes and availability, some of the participants were changed, relying on suggestions on the most suited persons. Facilitation and preparation responsibilities were given to the participants according to the process description, leaving the researcher as mainly an observer of the situation. The parties with responsibilities in the workshop were familiarized with the model and its objectives beforehand by the researcher in the preparation of testing that is presented in chapter 7.3.1.

**7.1.1 Material collection and analysis**

The material collected comprised mainly of researchers notes, that were obtained through participant observation in the suggestion and development phases. In addition, the documents of the solution to be investigated were reviewed. The material collected was not transcribed as was done with the material collected from interviews, but the identified development suggestions were actualized directly in the process. The identified development suggestions and steps in process revision are described in detail along the testing process, after which the final process is formulated in chapter 7.4.

**7.2 Selection of solution to be investigated**

The selection of the building solution to review was done in collaboration with the researcher, the Head of design and the Design manager. As in the suggestion phase, the selection was restricted to modular solutions and the investigation of Fira’s own solutions was seen most feasible. In the Keinulaudankuja project, Building 3 currently in the design phase was planned to include Fira’s own bathroom modules called Modules 2.0. These modules had not been used in a project before, and the impacts were thus not known even though similar solutions had been used, such as the previous version of the product.

Because of this unfamiliarity and the objective to justify the solution also by its costs, Modules 2.0 was selected as the building solution to review with the process. One solution was considered to be enough in the testing of the process as the amount of solutions to review during the workshop could be increased once the process is standardized and familiar.

**7.2.1 Modules 2.0 bathroom module**

Modules 2.0 is a bathroom module developed by Fira, that combines the bathroom and building services (HVAC and MEP installations) in a single module. The modules can be installed on top of the slab or vertically in a shaft. The product is an upgrade to Modules 1.0, that has been installed in two projects by Fira and one by Skanska. Modules 2.0 comes in two versions that have mirrored layouts (Picture 2) of 4,5 square meters. The module includes the functions of the bathroom such as a toilet, sink, cabinets and shower as well as a space for a washing machine. In addition, the module includes ventilation ducts (either centered ventilation system or apartment specific ventilation), plumbing for the module and kitchen, manifolds and locks and a floor heating system (either water circulated or electrical) for the module. There is also a possibility to combine the module
with a 2,5 square meter sauna module either on the wall opposite to the bathroom door or on the wall opposite to the sink.

![Picture 2 Modules 2.0 element layouts.](image)

As the product has not been used in a project yet, there is no actualized cost information available. Some value calculations have though been made by Fira Modules, where the product is compared to an onsite built bathroom or a traditional modular bathroom. With these calculations, the indirect cost effects are attempted to be shown, so that the module would be appealing in spite of the more expensive direct costs.

Savings are believed to originate from five aspects:

- **Planning and design**: the need for architectural, building services and automation design is reduced. The plans are reusable in several projects. *Presumed savings 1058€/apartment.*

- **Building services (HVAC & MEP)**: The module holds a large part of the building’s HVAC and MEP systems as well as smart-building features. *Presumed savings 535€/apartment.*

- **Installation and site work**: Less work coordination because of the basically non-existent work inside the bathrooms, less material waste and coordination. *Presumed savings 720€/apartment.*

- **Total project schedule**: Can reduce the overall building time and the throughput of the project which influences project costs and financial expenses. *Presumed savings 2458€/apartment.*

- **Warranty and life cycle**: Clear and simplified warranty process, updates on module enable value adding services on the lifecycle. *Presumed savings 120€/apartment.*

*Presumed total savings 4909€/apartment.* (Fira 2019)

In spite of the calculations on presumed savings, the usage of the product is still questioned in Fira. The doubts often deal with the dependencies the modules set on other building parts and the actuality of the presumed savings, especially when used for the first times, as surprises are expected. In order to reduce these surprises and gain the benefits
and savings presumed, the impacts of the module and the created solution combinations need to be known and regarded already in the design phase.

7.3 Implementation and results

The implementation of the process was first carefully planned, after which the testing of it was carried out together with the professionals from the company. Minor modifications were made in the process during the implementation, that are described and justified below. The preparation of the testing and the structure of the workshop are first discussed, after which the course of the workshop is described in detail. The results are evaluated, and the obtained hierarchy is presented.

7.3.1 Preparation of testing

After selection of the building solution to review, the process and practicalities of implementation were thoroughly discussed with the Head of design. In the discussion, the suitability of the model was verified, and the participants and roles were further defined. As in the original process by Lehtovaara (2018), it was decided that the Head of design would hold the facilitating responsibility in the workshop, while the Design manager would be in charge of the preparations. The structure of the original workshop was seen to be mostly suitable also for this process apart from the time allocations for each phase during the workshop. As the building solution under review is unfamiliar to most of the participants, the time needed for introduction should be longer so that a thorough presentation of the characteristics of the solution could be held. Because of this was also concluded that the participants should include a representative from the company of the solution.

The participants were mainly selected among the interviewees, so that some familiarity in the research would already exist. In the selection, familiarity with Modules 1.0 and other bathroom modules was though favored, so that the participants would have the best prerequisite to evaluate the impacts of the solution. Due to some personnel changes and availability, some participants were changed from the interviewees. In these selections were relied on suggestions from other participants and professionals from the company. It was also decided that the open discussion and actual creation should last for 30 minutes instead of the planned 20 minutes, as going through the model would most likely take time. In addition, a brief introduction on the research was included in the beginning of the workshop and a detailed reflection in the end, that are not part of the workshop model in the future but are related to the research and evaluation of it. The structure of the workshop would thus be:

Introduction: 30 minutes

- Brief introduction of the research (10 minutes)
- Introduction on Modules 2.0 (10 minutes)
- Presentation of the hierarchy (10 minutes)

Creation: 30 minutes

- Open discussion (10 minutes)
- Supplementing the hierarchy model, impact analysis with advantages and red flags (20 minutes)
Follow-up measures and reflection: 30 minutes

- Defining the responsibilities and deadlines for follow-up measures (10 minutes)
- Reflection on the process and feedback (20 minutes)

The hierarchy model was prepared jointly by the Site engineer, Design manager, Accounting manager and Construction manager. The roles in the preparation of the workshop was discussed with each party, explaining the objectives and allocation of time for the preparations. It was concluded that the preparations, including formulation of the hierarchy model, should take about an hour of each party’s time like it did in the formulation of the model in the suggestion phase. In addition, power point slides (appendix 4) were prepared for the workshop, so that the agenda, goals for each step and decided aspects would be visible for the participants during the workshop. The slides were prepared by the researcher and can be used also in the future as a template in the workshops. The researcher also prepared a preparation guide document (appendix 5), where the responsibilities and tasks for each role were defined both before and during the workshop. These documents were handed out to the Head of design and Design manager one week before the workshop.

The preparations followed the formulated process model, with a few additive details. Even though the process model itself had been used in Fira before, the participants did not have experience from it and therefore the discussions relating to the allocation of responsibility in the preparatory phase were important. Although the preparations were decided to be on the responsibility of the Design manager, the researcher assisted by summoning the workshop and distributing the documents and agenda to the participants.

7.3.2 Workshop

The workshop was held in the head office of Fira 4th of April 2019 and it lasted for 1.5 hours. In addition, presentation of the research and gathering of feedback lasted for about half an hour. The participants and their roles in the workshop are presented in Table 5. All the participants were Fira’s personnel and were present in the workshop for the whole time.

Table 5 Participants in testing workshop.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Role in the workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of design</td>
<td>Facilitator, design expert</td>
</tr>
<tr>
<td>Site engineer</td>
<td>Cost expert (production perspective)</td>
</tr>
<tr>
<td>Accounting manager</td>
<td>Cost expert (design perspective)</td>
</tr>
<tr>
<td>Design manager</td>
<td>Design expert</td>
</tr>
<tr>
<td>Construction manager</td>
<td>Production expert</td>
</tr>
<tr>
<td>Operative manager, Modules</td>
<td>Solution expert</td>
</tr>
<tr>
<td>Researcher</td>
<td>Observer, assistant</td>
</tr>
</tbody>
</table>
In addition, the presence of a representative from solution development and quality/warranty was considered, but due to schedule restrictions no representatives from these departments were included. This was not considered to be a major issue, as the representative from Modules (in future Operative manager) would represent a solution expert and due to the novelty of the solution no real quality/warranty information would be available that the other representatives would not also be aware of. Including representatives from these departments could be included in the future if considered necessary.

**Introduction**

Introduction was divided into three parts that included presentations of the research and the solution, as well as a brief introduction on the hierarchy model. The presentation of the research lasted for the planned 10 minutes, after which the Operative manager took over to present the solution under review. The presentation included a review on the characteristic of the module including the measurements, incorporated technology and building service systems, mass customization opportunities and installation alternatives. In addition, the Operative manager, Head of design and Design manager discussed about the pricing of the module compared to the current quality standards. The presentation of the solution as well as the brief discussion lasted for about 15 minutes, which was slightly over the estimated time. After this, the hierarchy model was briefly presented, going through the structure that included the six main headlines (structural demands, installation, finishing, shipment and storage, design and quality/warranty) and the general functionality of the model without going into details and the identified headlines beyond the main headlines. As the mind map type structure was familiar to all participants, understanding the logic of the tree was easily comprised. Presentation of the hierarchy model took about 5 minutes, so that the overall time used for the introduction still remained in the planned timeframe.

**Open discussion**

After introduction was moved on to the open discussion. The discussion focused on the current use and prejudices of modular construction elements. As there has been moisture control issues experienced in the previously used bathroom elements, the Site engineer and Head of design discussed that there might exist certain prejudice against the use of the solution. It was also pointed out that because of the inexperience in the use of bathroom modules from both the main contractor and subcontractor sides, all the costs are not estimated correctly at the moment, but many contractors calculate a little extra just to be on the safe side. Generally, the participants concluded that the more prefabrication is introduced to the sites, the more benefits can be obtained. The open discussion took about 10 minutes, which was equivalent to the estimated time. The Head of design, Operative Manager and Site Engineer were mostly participating in the discussion. The Head of design facilitated the discussion only a little without interfering the course of the conversation or the people taking part in it. In this case this worked quite well, as the conversation did not drift from the subject and all of the participants got to articulate their thoughts, but the role of the facilitator could be more clearly defined in the future.

**Impact analysis**

The impact analysis focused on going through the prepared hierarchy model, supplementing it and finding the advantages and red flags. The model was gone through one headline at the time, starting from structural dependencies. Because the Design manager had not had time to prepare for the workshop, the researcher operated the hierarchy model using draw.io and entered the identified additions. Again, the Head of design facilitated the
conversation quite lightly and the researcher had to interfere in the conversation several times to keep the focus in the hierarchy model. It was also clearly seen that even though the general functionality of the hierarchy model was clear, identifying impacts in this type of manner was not familiar to the participants. Also the formulation of impacts was obtained difficult, as the participants could identify that there was some impact of a combination of solutions but could not precisely formulate it. An example of this is the direction of the hollow-core slabs, where the participants identified that the shaft installation of modules resulted in the direction not being able to be whatever, but the clear formulation of what it could be was not obtained. It could also be seen that because an impact was seen to be the result of many things, the participants struggled to find the actual causal connections between them. In the future the level of detail should also be more clearly formulated, as the participants identified some impacts, but considered them to be too minor to be documented in the hierarchy.

Most of the discussion was conducted between the Head of design, Design manager and Construction manager with the Operating manager making some considerations. The Site engineer and Accounting manager added a few details but did not actively participate in the overall discussion. In some cases, the conversation was stuck in an impact for a long time and the Head of design illustrated some scenarios on the white board. Because of this, going through the model took a lot more time than estimated, lasting for nearly an hour. Also, towards the end of the impact analysis, some parts of the hierarchy model were skipped because of the time already used in the model. This being said, the facilitator should take a stricter approach in directing the conversation, so that the focus would be in finding the impacts and their costs, without thorough explanation of all possible scenarios.

**Follow-up measures and responsibilities**

After the impact analysis, the facilitator led the conversation in defining the follow-up measures. The follow-up measures focused in ensuring documentation and furthering of the identified aspects not yet found in the design guide documents. The identified follow-up measures and responsibilities are gathered in Table 6.

Table 6 Identified follow-up measures and responsibilities.

<table>
<thead>
<tr>
<th><strong>Participant</strong></th>
<th><strong>Follow-up measure</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of design</td>
<td>Definition of policies that are to be favored in the company, such as the preferred alternative of installation of the module</td>
</tr>
<tr>
<td>Site engineer</td>
<td>Revision of the hierarchy model and design guide onsite to identify missing aspects in the design guide that should be added</td>
</tr>
<tr>
<td>Design manager</td>
<td>Documentation of the hierarchy model in the solution library or corresponding location</td>
</tr>
<tr>
<td>Operative manager, Modules</td>
<td>Supplementing the design guide with the aspects identified in the hierarchy model</td>
</tr>
<tr>
<td>Researcher</td>
<td>Distribution of the supplemented hierarchy model and follow-up measures to the participants after the workshop</td>
</tr>
</tbody>
</table>
The identified follow-up measures and responsibilities were documented in the power point presentation during the meeting so that the participants could see them directly. After the workshop, the supplemented hierarchy model and follow-up measures were also distributed to the participants via email. As this was now done by the researcher, in the future it should be defined to be on the responsibility of some other party, such as the Design manager or Project engineer.

In addition to the follow-up measures identified after the impact analysis, two development suggestions were found during the revision of the hierarchy model and recorded in the table alongside the hierarchy:

- Including Modules 2.0 logos on the protective covers of the modules that would serve as advertisements during transportation.
- Development of a cheaper module for rental apartments projects, where the material choices would not be as high-end as in the currently cheapest alternative.

The development suggestions were not allocated to be on the responsibility of any of the participants of the workshop but were only discussed as suggestions for the supplier. Therefore, they were included in the tasks of the Operative manager in the email sent after the workshop.

The definition of follow-up measures and responsibilities lasted for about 10 minutes, which was corresponding to the estimation. Because the current procedures and places for documentation in the company are presently under development, it was agreed that the hierarchy model would be documented in the solution library or corresponding place, after the reformation of the systems would be completed. After this, the best forms of documentation should be once more reviewed and the adequate file formats and locations decided.

Feedback and development suggestions

The last 15 minutes of the workshop were used for gathering of feedback on the workshop and the process as well as development suggestions. The observed development needs as well as the discussed suggestions are gathered in Table 7 below.

Table 7 Development suggestions and feedback.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Positive</th>
<th>Needs development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clearly introduced, the solution under review and idea of the hierarchy became familiar</td>
<td>The workshop could focus on a specific part of the hierarchy instead of the whole model</td>
</tr>
<tr>
<td></td>
<td>New aspects especially related to installation, previously unknown information now clear about the solution under review</td>
<td>Focusing more on the advantages, now analysis was mostly focused around the red flags</td>
</tr>
<tr>
<td></td>
<td>Good structure, easy to follow</td>
<td></td>
</tr>
</tbody>
</table>

69
<table>
<thead>
<tr>
<th><strong>Hierarchy model</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Positive</em></td>
<td>Easy to understand</td>
</tr>
<tr>
<td><em>Needs development</em></td>
<td>The hierarchy could be divided into smaller units so that it would be easier to visualize and present on the screen</td>
</tr>
<tr>
<td></td>
<td>Artificial intelligence could be incorporated to the hierarchy, so that parts of it could be hidden that would aid in focusing in one part at the time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Duration</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Preparations</em></td>
<td>People are extremely busy and finding time for preparations can be challenging</td>
</tr>
<tr>
<td></td>
<td>Insufficient preparations have a great impact on the success of the workshop</td>
</tr>
<tr>
<td><em>Workshop</em></td>
<td>More test rounds are needed to standardize the duration of the workshop</td>
</tr>
</tbody>
</table>

### 7.3.3 Solution combination tree

The supplemented hierarchy model was decided to be named a Solution combination tree. Even though all the main headlines were gone through in the workshop and impacts were identified under all of them, a lot of supplementing of the tree should still be done. Only a few elements were obtained to include a cost, and for example the building service systems requirements under installation headline were not discussed at all because of time restrictions. In the workshop, the participants discussed that a separate workshop could be held just on the building service systems impacts. This supports the finding that the Solution combination tree could be processed in parts in several workshops. The obtained Solution combination tree for Modules 2.0. is presented in Figure 24 below and a structural demands part of the model in Figure 25 and the design requirements part of the model in Figure 26. The identified prices in all three figures are hidden and replaced with ‘XX’ due to sensitive material.

Even though the aim of the workshop was to supplement the Solution combination tree as far as possible, continuous updating of the tree should be carried out. As considering the impacts of the solution prior to its implementation holds assumptions and speculation, the Solution combination tree should be updated once actualized information is available both on the costs and the impacts. Because of this, a Solution combination tree can never be considered ready, but as a continual process, where the level of detail keeps increasing. This is also supported by the DSR process, where the artifact is subject to constant development cycles.

The final selection of the solution combinations should be done based on the Solution combination tree and exploitation of CBA. In this case it can be seen from Figure 24 that the main selection of a solution combination deals with the slab and installation type selection. Other aspects identified have to do with matters that need to be recognized and
taken into account in order to make the installation or design easier, but do not involve a selection between different alternatives. The complete selection process is not illustrated in this research, but an example of the formulation of the combination of CBA and the Solution combination tree is presented in appendix 6.

Figure 24 Solution combination tree of Modules 2.0.
Figure 25 Structural demands in Solution combination tree.

Figure 26 Design requirements in Solution combination tree.
7.3.4 Evaluation of testing

After the workshop, the development phase and the development suggestions obtained in the workshop were evaluated. Based on the evaluation, the process is developed, and the final process is presented in chapter 7.4. All things considered, the development phase met the set objectives. The functionality of the artifact was tested in practice and the development needs were identified. The end users of the model were involved in the testing that provided knowledge on the usability of the model. The developed model was also obtained to be accounting for the problems identified in the research and improving the productivity issues in the residential construction unit of Fira, once the development suggestions have been executed and the process standardized in the use of the company.

The first development suggestion dealt with the impact analysis and amount of the Solution combination tree reviewed in the workshop. As the testing revealed that the whole model is too extensive to process in one workshop, especially if the time allocations are wished to be kept unchanged. Therefore, there should either be more time allocated for the impact analysis or the workshop should only cover a specific part of the Solution combination tree at the time. The hierarchy model was also suggested to be divided into smaller parts, that could be implemented for example by introducing artificial intelligence into the tree, so that parts of it could be hidden while processing others. This would help in focusing on one thing at the time and aid in presentation of the model on a screen.

The planned duration of the workshop was seen adequate, but also the twice as long duration of the testing was obtained to be functional. More test rounds would be required to obtain an effective duration for the workshop and a functional amount to review of the Solution combination tree. The time for preparations was generally considered to be suitable and the preparation document informative. In spite of this, the participants had not had time for the preparations, which also showed in the workshop in the form of insufficient facilitation and uncertainty of one’s own roles. The greatest threat for the model could therefore be concluded to be preparation, which when failed will have a great impact on the success of the workshop.

In general, the upfront type working method was obtained to be unfamiliar to the participants, who often considered that evaluating the impacts of the solution is impossible because of the lack of experience on the use of the solution. Therefore, most of the identified impacts dealt with things that had occurred either to the participants or that they had heard occurring to others. The upfront consideration of impacts could benefit from speculation on the most likely outcomes of solution combinations, that would adduce possible risks and red flags as well as combinations providing advantages. Because the main objective of the developed process was in fact to identify impacts of unknown solutions, a way to introduce constructive speculation in the process should be found out.
7.4 Summary and final process

The tentative process was tested regarding the preparations and the actual workshop. In addition, development suggestions were gathered, and the testing evaluated whereby the final process is formulated. The final process of selection of building solutions is presented in Figure 27.

![Figure 27 The final process of selection of building solutions.](image)

The outline of the final process was kept the same as it was in the tentative process with a few specifications and additions. Because of the importance of the preparation of the hierarchy, it was more clearly defined that the preparations are on the responsibility of the Design manager or Project engineer who involves other experts such as the Site engineer, Construction manager, Accounting expert and Solution development expert when needed. Instead of reviewing the whole Solution combination tree in the workshop, the Design manager or Project engineer decides what part or parts of the model are covered. The participants of the impact analysis workshop should be selected depending on the solution under review, so that the minimum requirement would include cost experts from the design and production perspectives, a design expert, a production expert, a facilitator and an expert of the solution such as a representative from the supplier or from the solution development department of Fira. The presence of a quality / warranty expert should be considered case-specifically.

The seventh chapter dealt with the development phase, that consisted of testing the developed process including the impact analysis tool. Based on the testing, the final process was formulated. The functionality of the process in the company was verified and meeting of the needs was confirmed. In the next chapter, the results of the research are summarized and discussed.
8 Discussion and summary

In this research, the selection process of building solutions in the design phase of residential construction projects was investigated. In order to increase the productivity of the projects, construction companies need to better understand the impacts of the building solutions and promote value-based selections. Even though tools have been developed for value-based selections, impact analysis is often completely lacking, thus resulting in selections where different aspects have been considered insufficiently leading to surprises and issues in the production phase. Therefore, a thorough impact analysis should be included in the design phase increasing predictability and more informative decisions.

The main objective of this research was to develop a process by which the dependencies and constraints as well as the direct and indirect costs of a specific building solution could be identified in the design phase of residential construction. The research was carried out in two phases. In the first phase a tentative process was formulated based on a literature review and semi-structured interviews conducted in the residential construction unit of Fira. In the second phase the process was tested in practice and the development needs were identified. Based on these, the final process was formulated. In this chapter the results of the research are summarized and evaluated together with the findings of the literature review. The objectives of the research are discussed together with the findings and the scientific contribution of the research is evaluated.

8.1 Evaluation of results

The objective of the research was addressed with three research questions (RQs), that were attempted to be answered with the existing theories in literature and the testing of the developed process. The first research question was formulated as follows:

*How could the dependencies and constraints as well as the direct and indirect costs of a building solution be identified and documented?*

In literature, the beginning of the design phase was obtained to be the most critical (Knotten et al. 2014) as the early decisions on building solutions set most of the project's final costs (Kankainen & Junnonen 2015) and restrict further building solution choices (Rosas 2013, Koskela 2000). In Fira, the design process was seen to follow the traditional method of constant adding of level of detail (Rosas 2013, Koskela 2000), relying on assumptions in the early stages of design. The process was also obtained to have contradictions in the intentions and acts, as the importance of the plans and their flawlessness was basically understood, but little efforts were made to achieve understanding of the impacts of the solutions. Also in literature, the biggest problems in the design phase in Finland’s construction industry were found in the flawlessness and compatibility of the designs (Junnonen & Kärnä 2015), even though the plans are known to dictate the success of the whole project (Mujumbar & Maheswari 2018). The extent of the design work is restricted by the budget and deadlines of the project (Haymaker et al. 2018), which would imply that a greater reassessment on the project’s resources and allocation of budget should be done. As the productivity of the construction industry is strived to be improved with the help of Lean methods, identifying these value-adding activities is essential. According to Bølviken et al. (2010), the value creation in the design phase is derived from variation, that is often considered contradictory to Lean principles. Improving this and promoting cooperation also central in Lean methods, the non-value-adding activities later in the project can be reduced.
The main focus of the design process should be shifted more to a front-end weighted manner, as also suggested by Aapaoja & Haapasalo (2014). In practice, this would mean allocation of more resources in the beginning of the project, so that resources could be reduced later in the project and rework prevented. The importance of early design involvement has been especially evident with modular building solutions (Peltokorpi et al. 2018b) but based on the results of the development in this research, it should be improved with all building solutions in order to increase predictability in the projects. As the projects are still often fragmented (Barbosa et al. 2017), the savings can be hard to perceive and the willingness to actualize future savings by greater investment in the present might be slim, because of the different entities carrying out different phases. The importance of the early stages of design can therefore be concluded to be not fully understood both in literature as well as in the case company, as processes and tools are developed, and resources used, rather on management of the situation than on lookahead planning. This was identified as a major factor for the developed process, that was linked to the new process model of Fira. The process was identified to be carried out at gate 2 between project planning and concept design and gate 4 at the end of project planning phase before moving over to detailed design. By involving the different parties in a collaborative problem-solving manner already in the beginning of the project, the far-reaching impacts of the solutions become known already in early stages and surprises later in the project are reduced.

A major factor in anticipating the success of different building solutions and the project is analysis of dependencies and constraints. In literature, the tools for identification of dependencies and constraints as well as indirect costs of building solutions were found to be basically nonexistent. Current evaluation was mainly based on experience and efforts of the person leading the design (Blismas et al. 2006), involving other experts when seen appropriate. This was also the case at Fira, where comparison and analysis of building solutions were mainly dependent on the Design manager and building solutions were selected based on assumptions of cost savings. Modeling the dependencies and constraints between the building solutions was found extremely difficult because of the large number of variations and options, which might for its part explain the lack of tools developed for this purpose. Also the indirect costs were found to be hard to forecast, as the costs might result from various sources depending on the project and situation. This could be seen to reflect to the undeveloped nature of construction, where several processes remain human centered and nondigital, resulting in poor knowledge accumulation and identification of root causes.

Because Fira is fairly new as a residential constructor, the uniqueness of the projects was particularly emphasized as many of the building solutions used were applied for the first time. As Fira is also highly focused in innovation and development, introduction of new building solutions is not uncommon, as could be seen from the already existing building solutions developed by Fira. Based on the interviews and suggestion phase, documentation of these solutions and their impacts had remained insufficient, amplifying the tacit knowledge and uncertainty in the company. Documentation of evaluation of a solution was often done only for one’s own benefit, leading to evaluation starting from the beginning in every project. The problem with the non-repeatability of the evaluation of building solutions was also identified by Koskela (2000), who suggested that a common way of documentation should be pursued in order to amplify learning. In Fira, no common tools were used and documentation on the selections were lacking. The current structural library was found to be insufficient, and the forms of documentation inconsistent. As also
concluded based on the literature review, the structural libraries itself are not a comprehensive tool for the Design managers, requiring also information on the impacts of combinations of different solutions (Bismsas et al. 2006). The created tool meets these requirements, as comprehensive analysis on different solution combinations is possible. As the documentation means in Fira were currently under development, no profound suggestions were made regarding the location and form of documentation, but these issues should be solved once the development of the systems is complete.

In literature, even though impact analysis was identified as a part of the selection process of building solutions (Haymaker et al. 2018), as in Fira, the analysis was seen to restrict to basic stability and constructability of the building, thus disregarding most of the actual effects. The developed model of impact analysis was obtained to aid both in visualizing the impacts as well as in documentation. On the other hand, the upfront consideration of impacts of previously unused solutions was found to be unfamiliar and unintuitive for the professionals in the company, who often considered that the impacts of a solution could not be considered, if there was no prior experience on the use of the solution. The same issue was found in literature, where selections relied on previous knowledge and if not available, assumptions (Haymaker et al. 2018). Finding the impacts of the solution was in fact obtained to be a lot easier in the suggestion phase, where the aspects that should have been considered but were not were pursued, compared to the development phase where the impacts that should be considered were attempted to be found. As the impact analysis is especially important for building solutions that are unfamiliar or previously unused, changing this mindset should be pursued. Traditionally, learning on the building solution selections has occurred through the feedback of the production phase as mentioned by some informants in the interviews. The lack of familiarity in the upfront consideration could be indeed seen as a cause for the slow development of the whole industry, as it promotes using the same solutions over and over, with little ability to justify or seek for new efficient combinations.

In literature, different types of hierarchy models were found to be supporting the visualization of dependencies and constraints between building solutions, as well as in displaying tacit knowledge (Cooke et al. 2008). An impact analysis tool in the form of a hierarchy model was developed and its usability in a project was tested. Constructing the hierarchy model was found to aid in the identification of dependencies and constraints as well as direct and indirect costs and the documentation of the Solution combination trees improves the situation, where impact considerations were project specific.

The impact analysis tool was identified to have development needs, that dealt with the usability and easiness of the tool. As the Solution combination trees were found to become quite extensive, incorporating artificial intelligence in the model would be beneficial. Using the tool to perform cost estimation of different alternatives would also require that automation and algorithms would be infused with the model. Generally, smart system integration in the tool would be a subject for future research.

The second RQ was mainly covered with the literature review and was formulated as follows:

*What are the viewpoints that need to be considered during the selection of a building solution? Which project parties should be involved?*

The selection of building solutions was found to be a process consisting of four steps that are problem formulation, alternative generation, impact analysis and value assessment
from which impact analysis was found to be insufficiently covered in order to ensure informative value-based selections. In Fira, the selection process of building solutions was not modeled at all, but all design managers had developed a process of their own, each emphasizing different steps. A thorough impact analysis that takes into consideration the dependencies and constraints as well as the direct and indirect costs of solution combinations was thought obtained to be lacking both in Fira as well as in literature. As the building solutions are different, determining the appropriate selection criteria and viewpoints should be defined case-specifically. Construction design process involves many different project parties with their own goals (Kankainen & Junnonen 2015). In addition, each designer is an expert of their own field only (Koskela 2000) leaving the entirety often unoptimized. Because of this, literature suggests involving also the production perspective in the design work (ICG Guideline 2015), that is believed to diminish reoccurring mistakes in designs (Rosas 2013). Because of this, collaborative models should be further introduced already in the early stages of design, involving the production phase professionals as well. Development of such model can though be challenging, as the matters under review are highly complex and the dependencies case dependent.

In literature, combining visual tools with different MCDM methods have proven efficient in the selection of building solutions (Cooke et al. 2008). The Solution combination trees produced during impact analysis are to be used together with CBA, and the two models were found to complete each other well. The developed model therefore completes the selection process of building solutions and ensures that the adequate things are considered during the final selection. As also found in literature by Chan & Chan (2014), the selections can however never be fully objective, as valuing the different aspects and alternatives are done subjectively, thus leaving room for opinions and debate. Therefore, even a ready evaluation can be dissatisfactory or incorrect in the opinion of another expert, thus hindering the reusability of the evaluations.

The variety in the viewpoints considered was also found in literature, where each model was seen to consider slightly different aspects (Zavadskas et al. 2018). The three most covered aspects in literature were material costs, life cycle performance and health and safety risks (Kamali & Hewage 2017, Zolfani et al. 2018). Even though in Fira the main consideration in the selection of building solutions was found to be the direct costs, it is likely that also the life cycle performance was considered in the restriction of possible alternatives and the health and safety risks in the construction site. Because the indirect effects were not defined in the course of the research, it is possible that the different experts in the company understood them differently. It was clear that the experts considered the recognition of different aspects as a part of the selection process, but generally could name only a few of them other than the direct costs. Because of this it is evident that the process could benefit of a more structured consideration of aspects common for all experts. The subjectivity on the importance of the aspects though made this hard, as some struggled to see why some aspects should be considered and thought of them as only wasting time. In addition, during testing of the model, the time constraints were identified as the main threat for the model, as insufficient preparation for the workshop will lead to unsatisfactory results.

The selection process of building solutions was found to be an extremely difficult process, because of the complexity of the product and the dependencies between the different tasks and variety of options. Because of this the entirety has to be considered at all times, that is contradictory to the overall design process, where the level of detail is seen to accumulate as the process moves forward (Rosas 2013, Koskela 2000). The selection of modular
building solutions was found to be especially demanding, as these often include more indirect advantages and cost benefits than traditional onsite built solutions (Smith 2010). On the other hand, modularization is seen as a strategy to control the dependencies and constraints between different building parts (Tee et al. 2019), but it can also create other new ones, which are equally important to acknowledge and consider. As the current evaluation and selection methods are still often fragmented and cost driven (Pan et al. 2012), the potential has been hard to perceive by traditional evaluation methods. In Fira, the usage of modular building solutions was in many cases based on business strategy and assumptions, with no real evidence on the actual benefits of the solutions. As in literature, also in Fira the viewpoints to consider in the selection of building solutions were not commonly agreed, but each decision maker based the selections on the aspects they found important. The aspects to consider were found to be hard to define consistently as the adequate ones could depend on the solution as well as project and overall situation. In the development phase of this research, six headlines were identified under which the aspects to consider could be grouped. The six headlines including design, structural dependencies, installation, finishing, quality / warranty and shipment and storage were found to be adequate in finding the aspects requiring consideration. In literature, the aspects were seen to cluster under three themes that were environmental, social and economic sustainability (Kamali & Hewage 2017, Zolfani et al. 2018). In future, the developed model could focus more on the combination of these aspects, as for example the structural dependencies might include several different alternatives that could be further considered from environmental, social and economic viewpoints.

The costs arising in the production and usage phases are often disregarded in the selection of building solutions, which has especially slowed down the uptake of prefabricated solutions (PasQUIRE & Gibb 2002, BliSMAS et al. 2006). Because of this, involving both a cost expert and a construction expert from the production perspective was essential in the analysis. It was also found, that involving the appropriate project parties is especially crucial in the impact analysis, which serves as the basis of CBA that can be done solely by the decision maker if the impacts are considered and described from various perspectives. In the development phase, the project parties involved in impact analysis should at its minimum include cost experts from design and production perspectives, a design expert and a production expert. In addition, an expert on the solution should be involved, such as a representative from the supplier. In the future, involving also the customer in the workshop process could be explored. The necessary project parties have not been identified in literature before, and the usage of cooperative models in this phase have been scarce. Because of this, more cooperation should be introduced already in the early stages of design, ensuring adequate consideration of viewpoints that would better represent the true qualities of the alternatives thus resulting in more informative selections.

In the future, the Solution combination trees could be developed to better illustrate the different viewpoints identified in literature, that would further aid in informative selections. As the tool currently highlights the advantages and red flags, visualizing the different viewpoints such as health and safety factors, environmental considerations and user experience and satisfaction among other things could be included. In the testing of the model different viewpoints were not required, but the identified aspects included the things the participants came to think of under the set headlines. Therefore, a stricter approach of identifying impacts from various viewpoints could produce a more detailed Solution combination tree. On the other hand, as found in the testing, the trees became rather extensive already with the current approach, which would suggest that without smart system integration this type of detailed evaluation would become overly demanding both in creation and usage of the model.
The third research question was:

**What aspects should decision-making on building solutions be based on?**

The selection of building solutions was ultimately found to be based on and determined by costs (Vihinen 2017). This was also obtained to be the most familiar decision-making criteria for the experts in the interviews. Therefore, in the impact analysis tool, a cost was pursued to be found to all identified impacts. The pros and cons of the indirect effects are also ultimately considered because of a cost effect, because of the business nature of the projects. As in many cases accounting of indirect costs have been done under a general cost category, such as operating and joint costs, cost overruns have been prone to occur in projects (Blismas et al. 2006). This cost accounting method amplifies the uncertainty of the true origin of the costs, that does not promote learning and actual cost information. This has also been experienced in Fira, where the selected building solutions have been presumed economical but because of all the indirect costs have in fact turned out to be more expensive than other alternatives. Relying on the direct costs as a final decision-making factor could result from the difficultness of modeling the indirect costs and value adding aspects. As there has not been sufficient methods to evaluate these means, making decisions on the grounds of what is known has been the most intuitive alternative. Even though in literature the selections are pursued to be done with value-based methods, the value could be in many cases turned into a cost saving either presently or in the future. Therefore, cost in all its forms could be concluded to be the definitive decision-making factor.

The direct costs of modular solutions are often regarded higher than of an onsite built corresponding solution. Even though this has been explained by the more extensive transportation needs and requirement of machinery and skilled workforce (Smith 2010) it could be argued that the comparisons are not actually taking into account the same aspects because of the different end result of the basically same product. As the traditional cost evaluation methods are limited and some of the costs buried in the operating and joint costs (Pasquire & Gibb 2002, Blismas et al. 2006), it could be argued that the cost estimates of modular prefabricated solutions can only be more accurate instead of more expensive. Thus, the problem is obtained to be more in the incorrect evaluation and estimation methods rather than in the decision-making factors.

The developed model strives to illustrate as many costs as possible for the different solution combinations. As illustrated in the example of using of CBA utilizing the Solution combination tree (appendix 6), the decision is not only based on costs but also on the advantages formulated based on the factors identified in the Solution combination tree. A broader consideration of the different viewpoints discussed earlier would also produce a broader range of factors leading to more aspects. As the different building solutions produce slightly different aspects, the underlying selection can be concluded to be based on the score of advantages and the total cost of the alternative. The valuing of the scores of the different alternatives in relation to their costs depend on the situation and require a somewhat subjective decision. This way of striving to find the indirect costs of building solutions has not been done in literature before and presents a novel method to make decisions on the building solution selections.

**8.2 Evaluation of scientific contribution**

The main scientific contribution of this research is the identification of the deficiencies in the building solution selection process as well as the developed impact analysis tool that
attempts to meet these shortcomings. In the literature review, the selection process of building solutions was found to be defined by some researchers such as Haymaker et al. (2018), whose formulation is used as a basis in this research. Even though many methods had been developed to ensure a multi-criterion, value-based selection, none of the methods had gained a solid foothold in the industry. The existing methods also did not recognize the consideration of dependencies and constraints between the different building solutions, hence ignoring the impact analysis that is a part of the selection process. The absence of the impact analysis has not been consistently identified before, even though Blismas et al. (2006) found that evaluation of different building solutions is often unstructured and person specific. No previous tools that aim in identification and documentation of the dependencies and constraints as well as costs of a specific building solution were found, but this type of knowledge was considered as tacit knowledge or professionality that builds up from experience. The upfront consideration of these was also found to be previously unattempted in such manner. Because of this, developing a tool to support impact analysis that aims in visualization of the dependencies and constraints, as well as the direct and indirect costs of building solutions is the greatest scientific contribution of this work. In addition, the development needs and suggestions provide new avenues for future research. The integration of the developed model with the existing selection method CBA also provides new perspective to the existing tool and its limitations.

The second significant scientific contribution can be seen to be the used research method. Even though DSR has been used in construction management and lean construction research, using it in the context of design management is fairly new. As the development and testing of the process were carried out in an actual environment, that is the residential construction unit of a construction company, the research provides a valuable reference of the success of this type of research in such context.

8.3 Managerial implications

Apart from the scientific contribution of this thesis, the main objectives included development of the current design process in the residential construction unit of Fira by modeling the selection process of solution combinations. The importance of this strategical aim has been especially evident in the residential construction unit, where the usage of the solutions has not been able to be justified and the unstructured selection methods have led to solutions creating cost overruns in projects. The developed model was adjusted to the needs of the residential construction unit of Fira, where the process was developed and tested in the Keinulaudankuja project, and the final process modeled based on the development needs arising from there.

The main managerial implication of this thesis deals with understanding of the effectiveness of the current processes and the importance of the allocation of resources in the construction project. Based on the results, it could be concluded that there are major development needs in the basic processes and documentation methods in the company. Even though Fira is fairly new in residential construction, it has a long experience of concrete construction, such as parking halls. Therefore, the lack of a working process cannot be fully explained with the lack of experience or novelty in the industry. If the research had focused on the investigation of a unit where from the company has longer experience, the results could be slightly different. As the processes would have had time to form, there might be seen more structured ways of acting in the selection of building solutions. On the other hand, precisely because of the long experience, the selections of building solutions would most likely be even more based on experience and tacit knowledge of the
experts. Thus, the problems with the lack of documentation and basing selections on assumptions could be amplified.

The findings of this thesis indicate that even the documentation of the selections of the building solutions is laborious, it is essential in order to prevent reoccurring mistakes and waste in the form of repetitive evaluations done for one’s own benefit. The project specific evaluations are also important, as the situations are always not generalizable from project to project. Documentation and the digitalization of selections is essential in order to make the selections of building solutions more transparent and justifiable, which amplifies learning on the company level. The gathering and utilization of cost data from previous projects to the benefit of future projects is important for the investors, that can be supported by digitalization and a more careful transcription of costs during projects. Value-based selections should be a norm in the industry rather than a solely direct cost-based selection, which can be supported by the means of the process developed in this research. Therefore, the research can be concluded to have met the objectives also from the managerial perspective.

The developed impact analysis tool can be argued to be especially important from the managerial perspective, as performing the analysis on alternative solutions the use of one solution over another can be justified that could be a base for strategical decisions of the company. Based on the analysis, solution combinations that are wished to be furthered or prevented on the company level can be identified thus increasing focus and accelerating learning in the selected combinations. The analysis enables strategical selections, as the viewpoints and advantages included in the analysis could be selected to reflect company’s agreements with suppliers, vision, environmental efforts and so on.

The use of prefabricated and modular solutions in construction projects creates a need for a reassessment on the allocation of resources in a project. As production can be moved to factories and conducted before moving onsite, resources should be moved from the end of the project towards the earlier stages. Also in the design process, a front-end weighted design process should be strived for and the designs should be furthered as far as possible investing in the flawlessness of the designs. This way ideally, production could be only assembly of larger modules with standardized interfaces, which requires less resources and problem solving onsite.

8.4 Limitations and sources for error

The study has some limitations regarding the generalizability and reliability of the results that need to be considered. The main limitations and sources of error are dealing with the selection of research methods and subject as well as the role of the researcher. In qualitative research, the evaluation of the research in terms of reliability and validity differ, but generally the measures for increasing the reliability of results are unanimous (Saaranen-Kauppinen & Puusniekka 2006). Validity is the extent to which the research measures the phenomenon under research. It establishes whether the results obtained meet the requirements of the scientific research method. Validity errors might result from the researcher seeing patterns incorrectly, asking the wrong questions or even the interviewees understanding the questions incorrectly. As the errors might result from various sources that are fairly subjective and hard to measure, proving validity is often seen as especially hard in qualitative research. (Hirsjärvi et al. 2014) The reliability of the results can be improved by detailed descriptions of the execution of the research so that the logic behind the for-
mulation of conclusions can be easily followed. (Janesick 1994) Reliability in the evaluation of the research is used to describe how replicable the obtained results are. (Hirsjärvi et al. 2014)

Kirk and Miller (1986) identify three factors to assess the reliability of qualitative research. Quixotic reliability refers to a situation where a method consistently but erroneously gives the same result. This can be observed amongst other things in interviews, where the interviewees provide answers that do not represent a truth but a so-called correct social behavior. Because also this research included interviews where the interviewees were expected to express their opinions, it might be that the stated views included aspects that were thought to be the one’s asked for. This could be seen in questions related to the necessity of the research and the current state of the process, as many interviewees suggested that the research would probably not be conducted unless there was something wrong with the current process.

Diachronic reliability refers to the stability of observations over time. This is especially hard in qualitative research, as the objects are changing over time, thus making the reproduction of the same circumstances extremely difficult. Also in this research, reproducing the same setting would be impossible thus most likely resulting in slightly different final results. Anttila (1996) though suggests, that the diachronic reliability could be seen to refer only to the reproduction of the same setting and conduction of the same analysis process without a need to end up in the exactly same conclusions, which are enabled with the detailed description of the process.

Syncronic reliability refers to the similarity of the observations within the same time frame, obtained with different means. In this research, several methods were used to formulate the conclusions. The combination of research methods generally increases reliability and diminishes the possibility of error as opposed to a research conducted relying on a single research method.

Furthermore, Kiviniemi (2015) suggests that the reliability of DSR can be reviewed through three criteria that are process validity, practical validity and generalizability. Process validity describes how well the process has been described and how consistently it has been executed. The research followed a clearly described process formulation that was executed as planned. Although most of the research was conducted by the researcher alone thus lacking outside supervision and quality management, the advisors and supervisor of the thesis provided insight on the critical steps of the process ensuring that the process was followed consistently. Also utilization of several research methods increases the reliability of the results obtained by the process.

Practical validity describes how well the obtained model meets the intended objectives from a practical perspective. The development needs in the selection process were based on the diagnosis of the problem, which resulted in the development of the impact analysis tool. The tool was developed jointly with the end users, so the end result can be concluded to meet the requirements and needs of the users. The process model formulated was tested with the users, by which the final process was modified so that it met the demands and criteria of the users. As the model was only tested once, repetitive test rounds would have increased the practical validity of the results (Kiviniemi 2015). Because of time restrictions of the research, this was not been able to carry out.

Generalizability is referred to the ability to utilize the produced model in other contexts. The produced model was formulated based on a broad diagnosis including a thorough
literature review, which included also other contexts such as non-modal building solutions and other forms of building than residential construction. Because of this it could be concluded that the model is utilizable also in other contexts, but the actual functionality in such cases should be verified for example by conducting a testing of the model such as the development phase of this research. As the model was developed for a specific organization operating in a certain field in a specific country, the situation could be still seen as inherently unique, thus making the generalizability of the results problematic. Increasing the generalizability could have been done by including several cases from other forms of building such as renovation or commercial construction or even construction in other countries. This was though limited by the time and resource restrictions of the research.

The semi-structured interviews also pose some limitations to the research. The researcher is strongly affiliated with the case company by being an employee both prior and during the research, which increases the subjectivity of the findings of the interviews and is a possible source for personal bias. In addition, the inexperience of the researcher both in conducting interviews and conducting research increases the possibility for subjective conclusions. Even though Saaranen-Kauppinen & Puusniekka (2006) suggested that the interviewees should be selected by expedient sampling, this type of selections were also increasing the subjectivity of the sample. On the other hand, careful preparation of the interviews and validation of the structure with the thesis advisors, tapping and transcription of the interviews are all increasing the reliability of the results as well as decreasing the risks for subjectivity. (Kirk & Miller 1986)

The use of participant observation in material collection produces issues regarding reliability of the study. As observations are always subjective (Eskola & Suoranta 2014) and making specific observations are dependent on the observer, the reliability of them are hard to verify. As Eskola & Suoranta (2014) though point out, making selective observations is necessary, as indefinite amount of observations make analysis of the material impossible and decrease the expediency of the sample. The reliability of the observations could have been increased with taping and transcription of the development phase, but because analysis of a group interview setting is much more laborious (Hirsjärvi & Hurme 2008), due to resources this was not done in this research.
9 Conclusion and possibilities for future research

In this research the selection process of building solutions in the design phase of residential construction was reviewed and modeled, a new tool to support impact analysis was developed and tested as a part of the selection process after which the results of the research were discussed and evaluated. In this chapter the conclusions of the research are summarized and the possibilities for future research presented.

The importance of the design phase, especially the early stages defining majority of the project’s costs, restricting future alternatives as well as enabling the use of prefabricated and modular systems was found to be currently not understood in the industry. Investing in front-end weighted design improves predictability and prevents rework and surprises later in the process. Therefore, effort should be directed in the restructuring of the resources in the construction project, so that resources could be reallocated from production into design. In the design phase, collaborative problem-solving methods involving experts from both design and production should be introduced shifting focus from reactive problem solving into proactive problem anticipation. This could be done by introducing impact analysis into the early stages of design, such as the process described in this research.

The selection process of building solutions is often poorly modeled leading to unique ways of acting and little learning from project to project. The greatest problems in the design process of residential construction can be in fact seen to be in the lack of basic standardized processes and documentation. Insufficient impact analysis and documentation on selection criteria and justification in its current form hinder accurate cost estimation and can be seen as one root cause for the productivity issues in construction projects. The current decisions were obtained to be ultimately based on the direct costs of building solutions, that has hindered the uptake of modular building solutions in construction projects and increased relying on tacit knowledge and assumptions regarding other aspects. Basing the decisions on direct costs was obtained to be the result of insufficient knowledge and evaluation methods developed for indirect costs and value adding aspects.

The selection of building solutions can be improved by standardizing the ways of acting both inside the company and in a broader context in the whole industry. Impact analysis should be introduced as a standard part of the selection process and supported by adequate digital tools. Improving documentation on the selection criteria and factors leading up to the selection enables reusability of the analyses and prevents reoccurring work between projects. This could be done by improving the tools available for documentation and management of different solution combinations. Currently with existing methods, the definition and predictability of dependencies and constraints as well as indirect costs of building solutions was obtained to be extremely difficult because of variation and subjectivity.

Including indirect cost knowledge and value adding aspects should be included in the selection criteria of building solutions rather than basing the selection solely on the direct cost comparisons of solutions. As though obtained in the research, construction is still primary a business activity, thus cost being the ruling decision criteria in any case. Therefore, a cost should be strived to find for the value aspects, advantages and risks as well. This was though obtained to extremely hard mainly because of the variance in possible scenarios and their likelihood in different projects. The tool developed in this research is pursuing to meet this gap in impact analysis but as obtained, in order to function as intended as a part of the selection process, it should be incorporated with smart system integration that also serves as a possibility of future research.
The usage of modular building solutions has been quite limited in residential construction so far. Adopting modular solutions requires investing in the early stages of project and because of the unfamiliarity still in the industry, a lot of research and development both in processes and suitability in existing practices. Therefore, initiating modular building solutions requires strategical objectives that justify the greater expenses in the beginning and can be thus often done only by companies with large enough volumes that support investing in future savings. As the benefits of modularization are amplified the more modular and sectional the product architecture gets, these first steps in adopting modular solutions are the hardest, as fitting one or a few modular units to a non-modular surrounding can even increase costs rather than eliminating them. Therefore, before modularization reaches the point where construction onsite is only assembly of large blocks with standardized interfaces, the development and adaptation of modular solutions in the industry will be at least partly based on strategy and investments made based on future expectations.

The identified possibilities for future research include three subjects regarding the developed workshop process and impact analysis tool as well as three subjects regarding the topic in general. The identified possibilities for future research regarding the process and impact analysis tool are:

1. **Incorporating smart system integration in the impact analysis tool**: Even though the basic formulation of the tool was obtained feasible, the usability and visuality was still obtained difficult. The tool is also rather manual and including automation for example in the calculation of the costs of different solution combination paths could be studied.

2. **Shifting the focus of the workshop from supplementing the solution combination tree into preparation of CBA**: If the preparations of the workshop that include preparation of the solution combination tree could be carried out so that the model would not need supplementation in the workshop, the feasibility of focusing on CBA in the workshop could be studied. Once the process becomes more familiar and there might even be solution combination trees that can be used as a template, the need for supplementing them in the workshop could be diminished. Then the workshop could focus on defining the criteria and assigning the numerical values describing the importance of advantages as these are also subjective and might vary depending on the project party.

3. **Impact analysis of non-modular solutions**: As the research was restricted to cover only the impact analysis of modular solutions, the usability of the impact analysis tool on a non-modular solution should be verified.

The identified possibilities for future research regarding the topic are:

1. **Cost difference between prefabricated modular building solutions and onsite built solutions**: The direct costs of prefabricated modular solutions was obtained to be greater than of the corresponding onsite built solutions. Because the solutions in the end comprise of the same pieces but the prefabricated solutions are produced in a more controlled environment with specialized workforce, the direct costs of it should in fact be less than of the onsite
built solution. Transportation of modular solutions is most likely more demanding than of the materials but including the need for logistics coordination costs and possibilities in faulty deliveries, the total costs require more detailed research. This is also the case for other value-based assumptions.

2. **The effect of modular solutions on the resource needs in projects:** The usage of modular solutions in construction projects are presumed to add the need for resources in the beginning of the project but in turn require fewer onsite. The effect of modular solutions in the total resource needs and the manner of it should be verified with future research in order to know how the resources in the project should be allocated to result in the most efficient outcome.

3. **Decision-making motives and structures in design phase of construction:** In this research the aspects that decision-making is based on were studied, but the true motives and decision-making structures remain unstudied. As the professionals are rather limited to a certain perspective and areas of expertise the risk for sub-optimization is evident. On the other hand, the professionals in charge of the big picture can be rather estranged from the actual working, thus basing decisions on different factors than the professionals actually performing the work. These contradictions in the motives, possible hidden agendas of professionals and divisions in decision-making is yet to be studied.
References


Janesick, V. J. (1994). The dance of qualitative research design: Metaphor, methodolatry, and meaning.


Appendices

Appendix 1. Selection criteria in MCDM research. 1 page.

Appendix 2. Semi-structured interview structure. 2 pages.

Appendix 3. The hierarchy model for Noppaparveke balcony. 1 page.

Appendix 4. Presentation slides for impact analysis workshop. 3 pages.

Appendix 5. Preparation document for impact analysis workshop. 3 pages.

Appendix 6. An example of CBA utilizing the Solution combination tree. 2 pages.
### Appendix 1: Selection criteria in MCDM research

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Participatory</th>
<th>Data-driven</th>
<th>Efficiency</th>
<th>Fairness</th>
<th>Practicality</th>
<th>Transparency</th>
<th>Usability</th>
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<td>X</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Reliability</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*Note: X denotes the criterion is applicable.*
Appendix 2: Semi-structured interview structure

1. Introduction, position and background of interviewee
   1) How long have you been working at Fira / in your current position?
   2) What are your tasks and areas of responsibility?
   3) How do you see the level of design and design management currently at Fira?

2. Standardized solutions, present state
   1) Does Fira have standardized solutions that are pursued to be used in residential construction projects at Fira?
      a) How is a (new) design solution introduced in a project?
      b) How does the project end up in a specific design solution?
   2) Are there other standardized solutions from which the design solutions of a project are picked?
      a) Where can these solutions be found?
      b) What type of information is available of the solutions?
   3) Are there any specific building solutions with which particular or reoccurring problems have been experienced (in design/at site)? Are the problems related with the building solution itself or with combining it to other solutions?
   4) Are there any specific building solutions with which particular successes have been experienced (in design/at site)? What are the main factors for success?

3. Analysis of dependencies and constraints
   1) How are the dependencies and constraints of a specific building solution investigated or analyzed in the design phase?
      a) What project parties are involved?
      b) Do you think the analysis is sufficient and is it performed in the right way?
         1. How is it decided what aspects are left for the site personnel to solve?
      c) Do you think some building solutions should be further investigated? Examples?
         1. How could the building solutions requiring further investigation (most critical building solutions) be identified in the design phase?
   2) What are the different aspects considered?
      a) Do you think these aspects are sufficient?
      b) Are there other aspects that would require consideration so that the project would be more successful as a whole?
3) What tools are used to analyze different building solution options? (BIM?)
   a) How are these tools utilized?
   b) Are these tools sufficient?

4. Analysis of costs
   1) How are the direct and indirect costs of a building solution analyzed in the design phase?
      a) Do you think the current analysis is sufficient?
      b) How far are the indirect costs of a building solution identified / recognized?

   2) How are the costs noted in the selection of building solutions?
      a) What criteria affect the selection? (Is the cheapest one always chosen?)
      b) How are the potential risks noted?

   3) What tools are used to analyze the costs of a building solution?
      a) Are these tools sufficient?
      b) Does the costs analysis of a project include cost knowledge from previous projects?

5. Utilization existing knowledge / data
   1) What data should be reviewed to gain concrete data on the formation of costs from the dependencies and constraints of a building solution?
      a) What should be looked for in order to know how well the costs from dependencies and constraints have been anticipated?
         1. Where can the unanticipated costs or effects be seen?
      b) Where can this data be found?

   2) Is data gathered during the construction phase that would aid the investigation of dependencies and constraints of a building solution in the design phase?
      a) How do you think this type of data is utilized currently?

6. Ending, free word
   1) Can you think of something else related to the subject that you would like to discuss?

   2) Do you think the tool being developed in this research is necessary?

   3) Who else do you think I should interview?
Appendix 3: The hierarchy model for Noppaparveke balcony

The identified prices are replaced with ‘XX’ due to sensitive material.
Appendix 4: Presentation slides for impact analysis workshop

**AGENDA**

- **INTRODUCTION** (20 minutes)
  - The building solution under review and the formulated hierarchy model is presented

- **OPEN DISCUSSION** (10 minutes)
  - The participants articulate their opinions and experiences of the building solution

- **IMPACT ANALYSIS AND SUPPLEMENTING THE HIERARCHY MODEL** (20 minutes)
  - The formulated hierarchy model is reviewed one topic at the time, the advantages (green boxes) and red flags (red boxes) are identified and marked

- **FOLLOW-UP MEASURES AND RESPONSIBILITIES** (10 minutes)
  - The follow-up measures are defined and the responsibilities and deadlines for execution are set
INTRODUCTION (20 MINUTES)

- PRESENTATION OF THE BUILDING SOLUTION (10 minutes)
- PRESENTATION OF THE HIERARCHY MODEL (10 minutes)

OPEN DISCUSSION (10 MINUTES)

- **AIM**
  - The participants articulate their opinions and experiences about the building solution

- **DISCUSSED MATTERS:**

  - **PROJECT ENGINEER / DESIGN MANAGER**  
    - comment
  
  - **SITE ENGINEER**  
    - comment
  
  - **HEAD OF DESIGN**  
    - comment
  
  - **SOLUTION DEVELOPMENT ACCOUNTING**  
    - comment
  
  - **CONSTRUCTION MANAGER**  
    - comment
  
  - **OTHER**  
    - comment
**IMPACT ANALYSIS [20 MINUTES]**

- **AIM**
  - The formulated hierarchy model is reviewed and the advantages and red flags are identified, the hierarchy is supplemented whenever needed

- **IMPACT ANALYSIS**
  - Draw.io

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**FOLLOW-UP MEASURES AND RESPONSIBILITIES (10 MINUTES)**

- **AIM**
  - The follow-up measures are clearly defined and allocated to the participants of the workshop, including deadlines for execution

- **DISCUSSED MATTERS:**
  - PROJECT ENGINEER / DESIGN MANAGER
  - SITE ENGINEER
  - HEAD OF DESIGN
  - SOLUTION DEVELOPMENT / ACCOUNTING
  - CONSTRUCTION MANAGER
  - OTHER

*comment*
Appendix 5: Preparation document for impact analysis workshop

1 Preparation

1.1 GATE 2 / GATE 4

Project engineer / Design manager / Veritas manager

- Review of plans, identification of unknown or previously undocumented building solutions
- Selection of one building solution together with the head of design to be prepared and analyzed

1.2 AFTER SELECTION OF BUILDING SOLUTION

Project engineer / Design manager / Veritas manager

- Agreeing the time and participants for the workshop
- Preparing an introduction of the building solution (around 10 minutes) or contacts a representative from the supplier of the building solution and invites them to the workshop to present the solution.
- The main focus in the introduction is combining the building solution to the affiliated structures (structural dependencies), installation and finishing, shipment and design demands
- Finds the design instructions and / or other documents to distribute to the participants
- Prepares the hierarchy model with the help of template
  - Utilizes the expertise of the site engineer / accounting / solution development / construction manager to construct the model
  - The advantages are marked with green (advantage = other than a cost advantage)
  - The red flags are marked with red (red flag = not preventing the selection of the solution combination but includes issues that require special consideration)
- Summons the workshop and distributes the introduction, documents and agenda to the participants

Head of design

- Assists in the preparation of the introduction if necessary
- Familiarizes the introduction, prepares to facilitate the workshop

Site engineer

- Assists in the preparation of the hierarchy model if necessary, indirect costs

Construction manager

- Assists in the preparation of the hierarchy model if necessary, structural dependencies – production perspective

Accounting

- Assists in the preparation of the hierarchy model if necessary, direct costs

Solution development

- Assists in the preparation of the hierarchy model if necessary, structural dependencies – design perspective

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2 Workshop

2.1 COURSE OF WORKSHOP

- The time reserved for the workshop is 1 hour
- The workshop consists of four parts:
  - Introduction, presenting the solution (20 minutes)
  - Open discussion (10 minutes)
  - Impact analysis (20 minutes)
  - Follow-up measures and responsibilities (10 minutes)
- Goals for the workshop:
  - Introduction: The participants are aware of the structural elements of the building solution, how it is combined with other solutions, how it is installed, and the facts related to shipment that should be noted
  - Open discussion: The participants bring forth their opinions and experiences of the solution / a corresponding solution
  - Impact analysis: The hierarchy model is supplemented as far as possible, the advantages and red flags are identified and marked, and the identified development suggestions are documented in the table
  - Follow-up measures and responsibilities: The identified follow-up measures and timetable for their execution are divided among the participants. Follow-up measures can include documentation, announcements, forwarding the development suggestions...

2.1.1 Introduction

Head of design (facilitator)
- Defines the bookkeeper (for example project engineer)
- Presents the structure of the workshop, the agenda and the goals for the workshop

Project engineer / Design manager / Version engineer
- Presents the building solution under review and its features, if necessary a representative from the supplier of the building solution is invited to present the solution
- Presents the formed hierarchy model (general presentation, the goal is to understand the structure of the tree and its operating principle)

2.1.2 Open discussion

At participants:
- Articulate their opinions and experiences of the building solution under review

Bookkeeper
- Documents the surfaced issues

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2.1.3 Impact analysis

**Head of design (facilitator)**

- Leads the impact analysis: The hierarchy model is gone through one headline at a time, the impact chains are strive to be identified as far as possible, auxiliary questions:
  - What are the requirements for the application of the building solution?
  - What are the effects of the building solution?
  - What building solutions are affiliated to the building solution under review? What are the effects of the solution combinations?
- Ensures that the review progresses effectively, and that the conversation does not drift too far from the subject

**All participants**

- Participate in the impact analysis

**Bookkeeper**

- Documents the supplements in the hierarchy model (draw.io), marks the advantages in green and red flags in red

2.1.4 Follow-up measures and responsibilities

**Head of design**

- Steers the sharing of responsibilities and defining the schedule to carry out the follow-up measures

**Bookkeeper**

- Documents the follow-up measures and the persons responsible for their execution
Appendix 6: An example of CBA utilizing the Solution combination tree

The following is an example of the use of CBA method to make the selection of a slab out of the identified three alternatives as well as the selection of the installation method out of the available two alternatives. Because the example is only meant to demonstrate the combination of the Solution combination tree and the CBA process, the advantages and importance’s of them as well as costs of the different alternatives are hypothetical and do not represent the actual situation.

The CBA process consists of seven steps:

1. **Identification of alternatives**
   The different alternatives are identified in the Solution combination tree. In this case three different slab options are identified that all hold the two possibilities of installation methods. A separate CBA process could be carried out so that the slab selection would be separated from the installation method selection, but in this example, these are combined.

2. **Definition of factors relating to the alternatives**
   The factors can be defined based on the identified aspects in the Solution combination tree. In this example, six factors are defined, based on the aspects requiring consideration in the Solution combination tree.

3. **Definition of criteria**
   The criteria for each factor are defined, promoting easier, faster and more reliable combinations. The definition of criteria is always subjective.

4. **Description of attributes**
   The attributes for each factor are described. Numerical values are used when possible, otherwise the attributes are described as concisely and clearly as possible.

5. **Definition of advantages**
   The advantages of each alternative are defined, comparing to the least optimal alternative.

6. **Deciding importance of each advantage**
   The most important advantage is decided and awarded 100, after which all other advantages are compared to that and awarded 0-100.

7. **Evaluating cost data**
   The costs are evaluated by following the hierarchy steps of the specific alternative in the Solution combination tree.
After the seven steps, the total score of the benefits and the total costs are considered, and the alternative providing most benefits (highest score) that fits in the project’s budget is chosen. Based on this example, the thinner hollow core slab and on slab installation would most likely be chosen, as the benefit score is 50 points more than the next best alternative while the total costs are only the second highest. As being said, the example does not represent the true situation regarding the total costs and other considerations but is demonstrating the combination of the Solution combination tree and the CBA process, therefore not necessarily resulting in the truly best alternative.