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MASTER'S THESIS

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PREFACE

This thesis marks the end of a master's study in Industrial Economics at The University of Stavanger (UiS). It has been written in collaboration with Total Betong AS.

The thesis corresponds to 30 credits per student and has been completed over 20 weeks during the spring semester 2023. The authors are Lageeshan Sathiskumar and Agaash Sivakumar.

The choice of issue was dependent on a topic which will be to further use when our working careers start. The factors that are reviewed in this thesis are highly relevant for the construction industry.

We would like to thank Total Betong AS, especially Berit Maudal and Kurt Helland, who helped us find a relevant issue as well as providing with sufficient resources. In addition, the interviews with key personnel in the construction industry were very helpful.

Finally, we would like to thank our supervisor from UiS, Sigbjørn Landazuri Tveteraas, who has contributed with ideas and help forming this thesis. Furthermore, we want to thank Chandima Ratnayake and Samindi Samarakoon for support and advices regarding the analysis methodology.

Stavanger, 15. June 2023

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ABSTRACT

This thesis is written in collaboration with Total Betong AS, a turnkey contractor in Norway, who has a vision to build better underground parking spaces under apartment buildings at a lower cost. It is also a governmental goal as the need for parking spaces under new apartment buildings is constantly increasing and the value of a parking space is quite significant ranging from NOK 200 000 - NOK 700 000 (Marschhäuser, 2020). The challenge at hand is to obtain an additional parking space by selecting a building method that ensures efficient space utilization while adhering to schedule and budget constraints.

There are several construction methods when building a concrete structure, but in this study, we focus on cast-in-place concrete, prefabricated concrete, and a combination of both. Cast-in-place concrete involves creating formwork shapes with reinforcement and subsequently filling them with fresh concrete on-site. On the other hand, prefabricated concrete refers to elements produced in a factory under controlled conditions. These elements are then transported to the construction site for Just-in-Time delivery and installation.

In addition to the quantitative factors of time and cost, there are various qualitative factors that influence the choice of building method. Hence, it has been useful to use an analysis method that combines both qualitative and quantitative factors. The Analytic Hierarchy Process (AHP) is a multicriteria decision-making process that attempts to select a building method based on input from experienced stakeholders with relevant knowledge of such projects. Questionnaires were sent to experts to select critical factors for the choice of building method, and further assign them a degree of importance in relation to each other. This way, we also get an objective answer based on subjective opinions.

Research shows that productivity levels are lower in the construction industry than in other industries, while costs and conflict levels are increasing. For these reasons, interest in Lean techniques and tools has increased to promote collaboration, communication, creativity, and risk reduction. This thesis therefore explores how these techniques can identify dependencies throughout a construction project. Lean tools such as the Last Planner System (LPS) and Pull-Planning techniques are effective when discussing criteria that determine the choice of execution methods. This can reveal that some factors are more important than others, which can immediately rule out a building method.

The study primarily employs qualitative research methods, including an extensive literature review and a case study involving three reference projects. Two of the reference projects have been completed, while the third project is ongoing and has been utilized for the AHP analysis. The case study incorporates various data sources, such as project documents, tenders, semi-structured interviews, and site visits, to gather comprehensive information.

From the AHP analysis, it emerges that prefabricated concrete is the preferred choice of the design team for the latest reference project, Bykronen. HSE, quality, and operational flexibility dominate the choice of construction method compared to the usual factors such as cost and time. From the interviews and case studies, it emerges that column-free spans and large wall and roof elements are desirable as they allow for more parking spaces and better parking utilization. It is therefore concluded that parking basements are particularly well suited for construction with prefabricated elements as it has a great potential for improvements in all construction phases while reducing the indirect costs that can be significant in traditional construction with casting.

Every decision should be grounded on project-specific considerations; however, valuable insights and lessons can often be transferred from one project to another.

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Chapter 1: Introduction

This chapter provides an overall overview of the thesis, where the background of the thesis, issue, purpose, and limitations are introduced. Finally, the structure of the assignment will be reviewed.

1.1 BACKGROUND

Since the year 2000, the construction industry has experienced a 10% decline in productivity and efficiency. This has led to an increased focus on this in the modern construction industry. (Steinar Toddsen, 2018). The industry has the impression of the outside as being slow when it comes to adopting innovations and is facing increasing pressure to improve efficiency, reduce waste, and deliver projects within budget and on time. In this context, choosing the right concrete building method is crucial for achieving these goals. Although there are many types of concrete and additives, there are mainly two approaches to the industrialized construction of concrete parking garages, which have been used since the 1950s: offsite prefabricated elements and cast-in-place constructions (Nobi, 2014).

Construction is a large and complicated process, and it is very difficult to determine how an innovation might impact the existing processes without testing it practically. This uncertainty indicates that the barriers to adopting new innovative methods in construction are substantial, hence the need for a Lean culture within the workers and the company. The value chain for a parking garage project is interconnected and depends on effective communication and collaboration among the different stakeholders. The communication lines can be improved by applying Lean Construction tools and techniques (Howell).

This thesis gives an in-depth analysis of the advantages and disadvantages that come with the two methods for parking garages. Based on three reference projects, the thesis will use the Analytic Hierarchy Process (AHP) to analyse the multi-criteria problem. The AHP software, Expert Choice, was used for the analysis. It requires project-specific input and knowledge of influencing factors to recommend whether prefabricated elements or cast-in-place concrete is the best solution for the specific project. The angle is mainly from a general contractor's point of view, with some input from the prefabrication suppliers.

1.2 PURPOSE AND RESEARCH OBJECTIVE

This master's thesis is carried out in collaboration with Total Betong AS, which is a general contractor that develops and delivers all types of construction and facilities (Total Betong, 2023). Total Betong aims to construct parking garages under apartment blocks that are both high-quality and cost-effective. Additionally, they strive to enhance their expertise in all phases of a construction project, including the planning phase, engineering, construction, and operation. Three reference projects have therefore been given as a basis for case studies.

The research objective of this thesis is to determine whether cast-in-place concrete structures or prefabricated concrete elements are preferred solutions for parking garages beneath apartment buildings. Challenges and experiences will be evaluated using literature reviews and other qualitative research methods. Construction projects are often complicated, several actors with different disciplines are involved, and the activities of the various disciplines are linked to each other, which can lead to difficulties in cooperation. By adopting tools based on Lean Construction, it will be possible to involve the actors early and detect possible conflicts in advance and not during the actual execution. The intention is not to arrive at a definitive answer but to see the connection between several construction projects and make it easier and cost-saving for similar projects in the future.

Further research questions:

1. How can Lean Construction principles and tools be applied to optimize the decision-making process for choosing the right building method for parking garages?
2. What are the key factors when choosing a construction method for parking garages?
3. To what extent are parking garages under apartment blocks suitable for construction with prefabricated elements?

Companies and stakeholders have different perceptions of Lean. The concept is seen as a management philosophy among various enterprises, but this thesis will show how a collection of tools and techniques, or perhaps a combination, can help with decision-making while improving the corporate culture within companies in the industry.

1.3 LIMITATIONS

The choice between prefabricated and cast-in-place concrete constructions is extensive and has a lot of influencing factors. The time allocated for the work is limited to approximately 20 weeks, and therefore it will be necessary to limit the scope of the thesis.

Time, cost, operation, and effective planning are the focus areas. Maintenance and use of the buildings after completion have not been emphasized but should still be considered in the planning phase when choosing between the execution methods. The thesis only concerns the construction process from the perspective of the contractors without influencing technical disciplines. The elements included in the thesis are mainly slabs, outer walls, and other load-bearing elements which are used in given reference projects. Doors and windows for outer walls have been excluded, and for slabs, ground floor slabs are omitted as the focus is on asphalting of the cast-in-place foundations.

To conduct the analysis, questionnaires were distributed to the design team involved in the ongoing reference project, Bykronen. Although more respondents were desired, the number of participants was limited to three due to time constraints among the designers.

This thesis will, among other things, shed light on how Lean Construction principles can change Total Betong in terms of involvement in the planning phase, overall thinking, and employee empowerment in a construction project. The Lean term has many aspects beyond this, and we will in the theory section attempt to delineate the theme and draw parallels for the research objective.

1.4 OUTLINE

In this thesis, we have used the following layout:

- **Chapter 1:** *Introduction* – the master's thesis begins with an introduction to the issue, including research questions and the purpose for the choice of the issue initially. Limitations and structure of the thesis are also presented.

- **Chapter 2:** *Theory* – a review of the literature and tools that provide the basis for the discussion chapter later in the thesis. Starting with an examination of Lean Construction principles and associated tools, followed by a comparison of the two building methods. Necessary to answer the research questions and research objective.

- **Chapter 3:** *Methodology* – this chapter is split between research methodology and analysis methodology. Research methods are presented first, with their strengths and weaknesses. The reference projects are later described before introducing the analysis method: Analytic Hierarchy Process (AHP). One of the reference projects is also used as a slightly more comprehensive example for the analysis part.

- **Chapter 4:** *Results and Discussion* – the results from the AHP analysis are presented and discussed. The second section examines the prerequisites for selecting a suitable solution by considering the results, interview findings, and the literature review

- **Chapter 5:** *Conclusions and Recommendations* – this chapter summarizes the whole thesis. The research questions and research objective are answered. Finally, the contribution of the study and suggestions for further research are presented.

Chapter 2: Theory

This chapter introduces the relevant theories and concepts to answer the research objective. Firstly, a description of many Lean strategies and tools for management that are applicable to construction projects and particularly answering the research objective. Secondly, a brief introduction to concrete as a building material followed up with the pros and cons of cast-in-place concrete and prefabricated concrete elements.

2.1 LEAN CONSTRUCTION

One of the main challenges in today's construction industry is the ever-increasing complexity, which entails an increased amount of information. This is challenging, especially in the design process of a building project, and it requires the traditional way of working and thinking to be changed. One approach for improving the situation is Lean Construction. Lean is known as a westernization of the Japanese concept known as the Toyota Production System (TPS), developed in the early 1950s by the industrial engineer and manager of Toyota Motor Corporation, Mr. Taiichi Ohno (Clayton, 2015). The concept of work from the Japanese was about the sense of equality, desire to improve, being cross trained across multiple departments, and centring their daily living on work. These traits differed from the traditional way of working across multiple industries, especially in Europe and America (see Table 1).

Currently, 70% of projects are delivered late and are over budget (Institute). A lack of trust between architects, engineers, contractors, and other providers has imposed significant waste into the delivery system. Lean Construction seeks to solve these problems in the industry. Research conducted by the Lean Construction Institute shows that projects with a high Lean intensity are more likely to be completed ahead of schedule and see significant cost reduction (LCI.Research). In the traditional way of working in construction projects, individual parties with separate contracts are only interested in the success of their part of the success. The risks involved are not shared, and it can lead to altercations if any issues arise. These traditional project delivery methods suffocate innovation because the incentive and willingness to improve any bad outcomes will harm their financial situations.

Table 1: Traditional Construction vs. Lean Construction

Traditional Construction	Lean Construction
Planners plan, and Doers do	Doers plan
Some must lose for others to gain	Everyone wins by reducing waste and increasing value
Competition is between individual companies for contracts	Competition is between the supply chains – tag teams
Produce everything and trying to empty it, can cause excess inventory	Produce and deliver goods and services when requested – Just in time
Innovation is dependent on: who pays and who gains?	Innovation is promoted – money and resources are moved where needed the most
Control is being reactive to negative differences – looking at reviews, then act	Control is proactively steering towards targets – doing what is needed to achieve objectives
Problems are unwanted and worthy of punishment	Problems are opportunities for learning

The purpose of Lean Construction is to design production systems to minimize the waste of time, materials, and effort to generate the maximum amount of value for the perceived customer. A deeper understanding of the potential benefits and drawbacks of both cast-in-place and prefabricated concrete construction processes are gained by combining Lean Construction principles to the research objective. We can also determine which approach may be more suitable and effective in the context of Lean Construction.

2.2 LEAN CONSTRUCTION PRINCIPLES

Lean, or continuous improvement, is in principle about making work processes more efficient. The methodology involves using different tools to help find sources of waste so that improvement measures can be initiated to remove this waste. The sources of waste can be detected by using different Lean approaches such as pull planning, Just-in-Time principals, and daily coordination meetings to name a few. These measures can help free up non-value adding activities and resources, and increase efficiency in the business, which ultimately creates the right conditions for increased customer satisfaction (Triangel).

The 5 Lean principles lay down the foundations of a Lean process. The principles are considered a guide for creating a better flow in work processes and developing a continuous improvement culture.

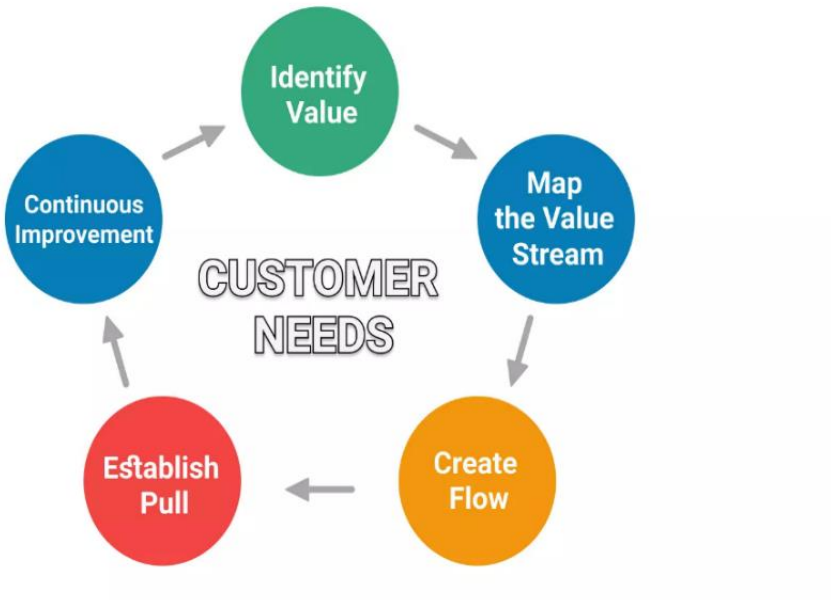


Figure 1: The 5 main principles of Lean (Kanbanize)

2.2.1 IDENTIFY VALUE

Lean thinking resolves around identifying value and eliminating waste. To understand what value is, it is important to discover the customers actual needs. The customer does not always know what they need, then it is essential to use qualitative or quantitative methods to uncover the exact need. Any activity that does not add value for the customer is a waste. There are many kinds of wastes in the manufacturing system that Lean eliminates (Heizer et al., 2017, p. 677). Table 2 shows the different sources.

Some waste activities are necessary to support value-adding ones while pure waste activities only damages the Lean flow of work (Kanbanize). In recent times, an eight source of waste has emerged, which is the poor use of employees' talents and skills. Proper utilization of different experiences and knowledge is important to achieve a culture with continuous improvement. The principle here is to create cross-functional Lean environment through the system.

Table 2: The 8 wastes of Lean (Skhmot, 2017)

Overproduction	Waste from making more product than what customers demand.
Waiting	Waste from time spent waiting for material, information, equipment, the next process to occur etc.
Inventory	Wastes resulting from excess products and materials that are not processed.
Motion	Wasted time and effort related to unnecessary movements by people.
Transportation	Wasted time, resources, and costs for unnecessary transportation. Faster shipping and assembly lines.
Defects	Waste from a product or service failure to meet customer expectations.
Extra-Processing	Wastes related to more work or higher quality than is required.
Unused Talent	Wastes due to underutilization of people's talents, skills, and knowledge.

2.2.2 MAP THE VALUE STREAM

«*Whenever there is a product for a customer, there is a value stream. The challenge lies in seeing it*» (Rother & Shook, 1999, p. 4).

A value stream map helps to see and understand the flow of material and information as a product is going through the value stream, including the supply chain (Rother & Shook, 1999, p. 14). This is the area many have struggled to implement Lean methods. The perspective of improving a value stream means working on the bigger picture, not just focusing on individual processes – improve the whole, not just optimizing some parts. By focusing on the bigger picture, we can also see the sources of wastes in the value stream, not only the waste itself.

Value stream mapping is very valuable since it ties together Lean concepts and techniques. It can be a planning tool, communication tool, and a tool to manage your processes (Rother & Shook, 1999, p. 19). Value stream maps are the blueprint for Lean implementation and for decision making in the design phase. No other tools show the link between information flow and material flow in the same way as a value stream map. Other quantitative tools and diagrams often gives us an urgency in the form of a measurement without showing us the root causes. A value stream map is good for describing what can be done to affect those measures.

The reference point is the customer’s value, and the goal is to identify all the activities that contribute to these values and distinguish them from what is considered as waste. This can be divided into the subgroups: non-value adding activities that are necessary and non-value adding activities that are not necessary. The former should be reduced as must as possible, and the latter should be eliminated. A visualization of its path is important to identify the value that your team produces for the customer.

The Gemba walk is an essential part of the Lean management philosophy (Kanbanize). In Japanese “Gemba” means where the real work happens, and its purpose is to allow leaders and managers to be where the value stream is. Every morning, Total Betong conducts a 'Toolbox talk' as their first activity of the day. Following the value chain will give you the best opportunities to identify areas of wastes. The main objective is to go through the value stream in detail and locate issues through active communication without judging employees, but rather being more collaborative and find problems together.

2.2.3 CREATE FLOW

Now that the activities have been identified and wastes are removed, the following action is to ensure the flow of these without delays or disruptions. Some strategies for achieving this: breaking down steps with the Last Planner System, reconfiguring the production steps, levelling out the workload, create cross-functional departments, and training employees to be skilled and adaptive across multiple departments. By focusing on creating a smooth flow, we can spot the bottlenecks in the processes. Bottlenecks are something that halts free movement and progress and alleviating them is crucial for the creation of a Lean flow. Flow can also be enhanced through construction planning meetings where team members regularly meet and set expectations for each day’s work. This concept will be further elaborated in the upcoming subchapter, which focuses on the Last Planner System. In this system, the work is broken down into distinct phases, allowing for a more detailed and structured approach to decision-making.

2.2.4 ESTABLISH PULL

After the creation of a smoot flow of work, the next step is to establish a pull system. The idea is to start work only when there is a demand for it – Just-in-Time delivery. In the construction industry, excess inventory of materials is considered one of the biggest wastes, and the goal is to produce the value that is needed by the customers and avoid overproduction. Excess inventory is also a sign of bad quality (Heizer et al., 2017, p. 688). A pull-based system allows for a Just-in-Time delivery where products are created at the time they are needed with the right quantities. This can be achieved efficiently by following the value stream and working backwards through the production system. Pull planning is an essential tool of the Last Planner System and is necessary for improving the flow of work and processes.

Pull Planning

Pull planning is a technique used to determine a completion date, based on the customer's needs. It is usually carried out with the main suppliers and the construction management team. The backward planning process considers resources that are available, this is the main difference between traditional planning methods. In that way, one can improve the understanding of various dependencies and remove non-value adding activities.

Pull planning is based on three steps:

- creating an overview of the client milestones.
- adding activities to be carried out with delivery dates.
- assessing the limitation of the activities.

After identifying milestones, the team works backwards to add the necessary details and requirements. A representative from each crew on the project is gathered by the general contractor or project manager to collaborate with sticky notes. It is one of the most effective ways teams can positively influence efficiency on a project (Granger).

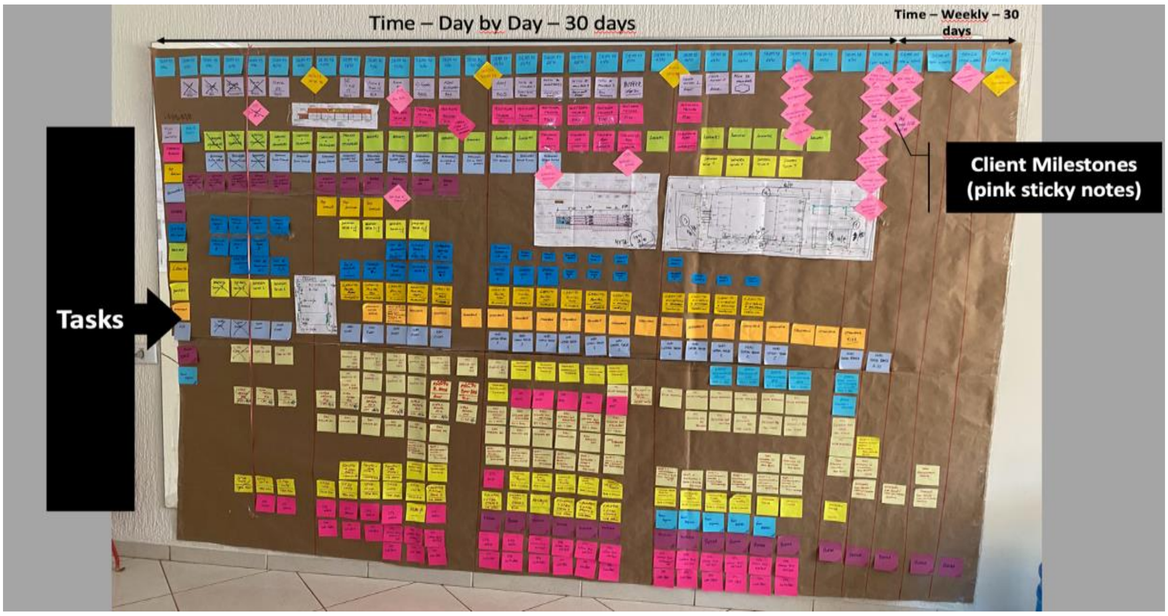


Figure 3: Pull Planning (Soares, 2022)

2.2.5 CONTINOUS IMPROVEMENT

First and foremost, respect for people is the cornerstone of Lean thinking. People transform ideas and materials in the final use of value. Respecting contribution of each individual and doing things right the first time is key. Second, Lean thinking is the constant reflection on value and determining if every resource is employed to generate maximized value. Third, Lean thinking commits to focus on process and flow through standardized practices that drives consistency and results. Forth, it encourages employees to constantly look for opportunities to identify and remove waste – find things that bugs them and fix them immediately (Institute).

The critic of Lean seems to resolve around the lack of focus on the human aspect, which can be related to the organizational culture. The process of implementing a Lean philosophy in a company is very complex and requires a lot of effort. Regardless of the size of the company, there is always an increasing demand for profitability and quality. Lean implementation begins first and foremost with leadership commitment and is sustained with a culture of continuous improvement. Experimentations and small incremental failures are allowed in order to drive innovation. This leads to the whole value stream and organization be improved and satisfied.

2.3 LAST PLANNER SYSTEM

The most significant and concrete aid Lean Construction has given the construction process so far, is the “Last Planner System (LPS)”, a planning system developed by Glenn Ballard. It is based on Lean Construction principles that allows the people who is closest to the work to plan the work for large and complex projects. The system allows potential hurdles to be detected and addressed before they slow down the flow (LCI, 2023). By using LPS, the engineering group reduces waste in the design phase, and can thus increase the value for the customer. The LPS should be seen as a series of values incorporated in a mindset, rather than a set of tools. The mindset and philosophy are what constructs companies their own versions. The system has become popular, largely because it has made plans more reliable and created stable lines of communication- and workflow.

In the traditional way of designing projects, on average, only 54% of work planned for a given week were completed within the schedule (LCI, 2023). This resulted with most projects being delivered late and over the allotted budget. The workers suffer injuries because of the rush of delivering the projects on time and stakeholders not being satisfied with the result. As this easily creates uncertainty and variation for all those who will carry out tasks further down the production chain, this provided the basis for breaking down the planning circle with frond end planning and production planning. Figure 4 shows a breakdown of the last planner planning cycle.

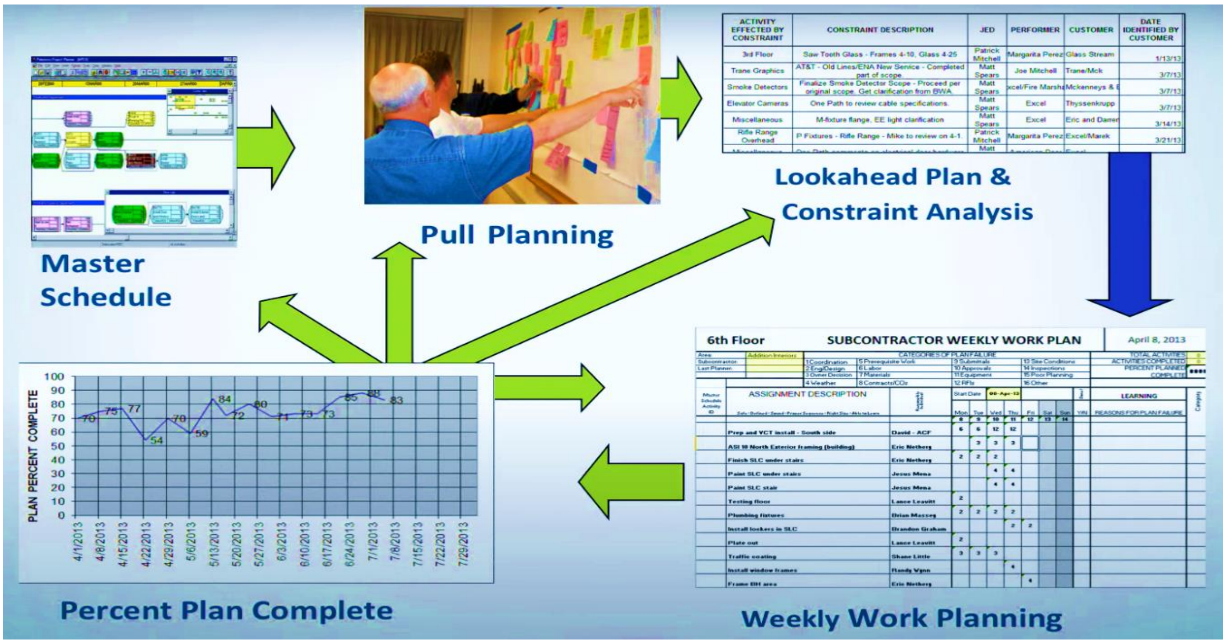


Figure 4: The Last Planner System (Education, 2020)

2.3.1 LAST PLANNER SYSTEM PRINCIPLES

The «SHOULD-CAN-WILL-DID» principle forms the basis for LPS and is divided into five stages. To be successful with the Last Planner system, all five stages must be executed (Tommelein et al., 2007, p. 12).

1. **SHOULD** is making the plans for a successful project completion.
2. **CAN** is focusing on ensuring the work can be done.
3. **WILL** is what each responsible crew member will do to fulfil the promises made in phase planning.
4. **DID** is reflecting upon how the project was and looking for opportunities for improvements for the next project or similar tasks.

The level of detail increases for every element and the first two has a longer planning horizon compared to the lookahead plans and weekly- and daily work plans. This system requires involvement and cooperation from the most important players in a construction project.

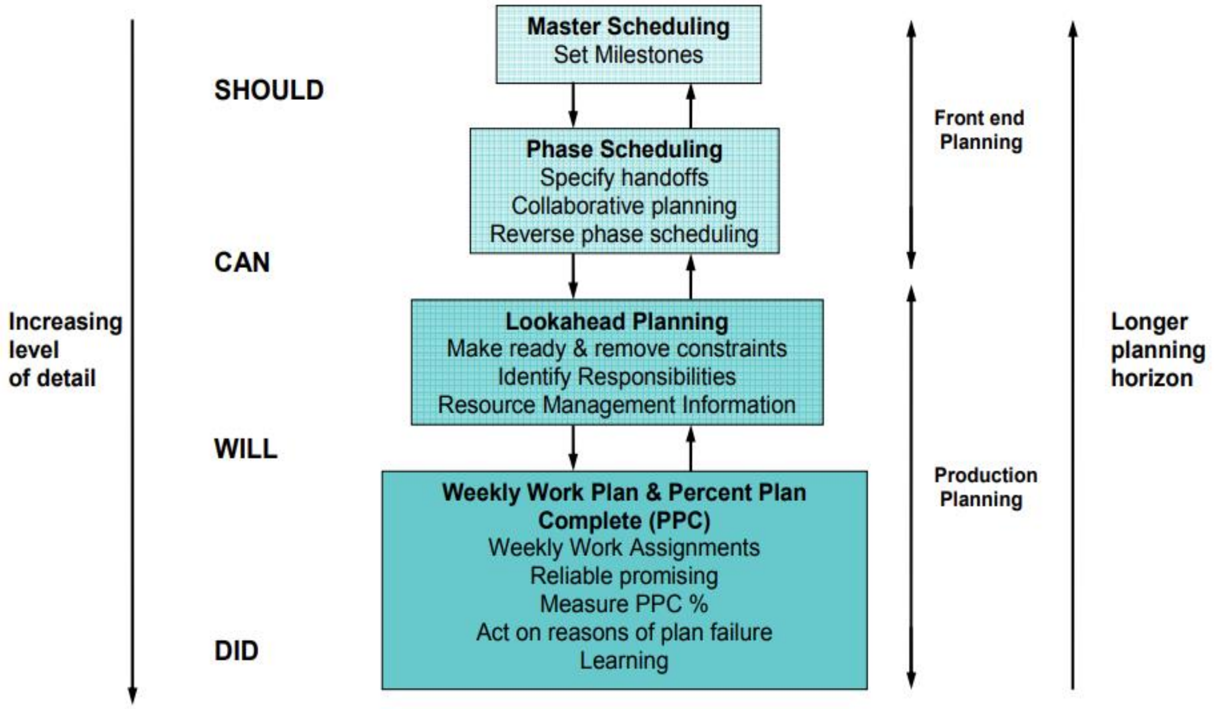


Figure 5: The Last Planner planning cycle (Tommelein et al., 2007)

1. **Master Scheduling:** during this phase, it is important to identify the most important client milestones that set the pace of the project and covers the entire project duration. It serves as a roadmap for the project. The uncertainty is quite large with a low degree of detail and mainly broken down by function, area, or product, depending on the project. The purpose is to establish the overall framework for subsequent planning, allowing the project team to identify potential constraints very early.

2. **Phase Scheduling***:* this phase is about dividing the master schedule into tasks and specified hand-offs. A hand-off is where one person releases an activity so that next person can take over. The phase planning also creates an agreement between the leaders from each team, the «Last Planners», about how the work between two phases is to be completed. Pull planning techniques help to ensure that the planning takes place in sufficient time before the design, without it, there is no assurance that the work is executed at the right time to achieve project milestones. Phase planning is done in meetings with the subcontractors and the workers get more ownership over the project by being involved in planning.

3. **Lookahead Planning:** in this phase, the phase schedule is usually divided into a six-week plan. The scheduled activities from the phase schedule are drawn into the lookahead process where they are broken into operational detail and made ready for assignment in weekly work plans. For example, phase schedule can be considered as a column and a lookahead plan is all the elements of the column, such as tie rebar, formwork, concrete pour etc.

   The pull-planning technique is also used here, where the plan is updated every week, so that new activities can be added. The master- and phase schedule is a part of the front-end planning process that covers all activities in the entire project. By contrast, the lookahead plan controls the flow of work and streamlines it for the Last Planner. Commitment is required in planning after evaluating SHOULD against CAN based on actual receipt of resources and completion of prerequisites.

4. **Weekly Work Plan & PPC:**

Weekly work planning is constructed by designers, construction foremen, and other supervisors with the highest level of detail. From the «Should-Can-Will-Did» principle, Weekly Work Plans are about the activities that CAN be carried out and transforming them into activities that MUST be done in the coming week, then reflecting upon what DID happen with the use of PPC indicators and constraints. The weekly work plan focuses on finding constraints and clearing obstacles. A constraint is when something interferes with a planned task and are written down in a constraint log, normally noted in weakly work plans along with PPC measures (see Figure 5).

Table 3: Constraints in construction tasks

Information	Drawings and descriptions must contain the correct information before work can begin.
Equipment	The equipment must satisfy the need for safety, load, and efficiency.
Material	The right quantity and quality of the material must be available.
Space	The workplace must be prepared and have necessary space for work.
Crew	Required skills and capacity to carry out necessary work.
External conditions	External conditions such as weather or public permits must be in place before the work starts.
Previous tasks	Previous activities must be completed with the right quality before the next ones get started.

Figure 5 shows a Weekly Work Plan that Total Betong AS has used for the reference projects given. Microsoft Excel with in-built VBA programming is used to create this format which gives a description of the activities with a timeframe. Who carried out the activity must be specified, and a reason must be given if the activity was not carried out.

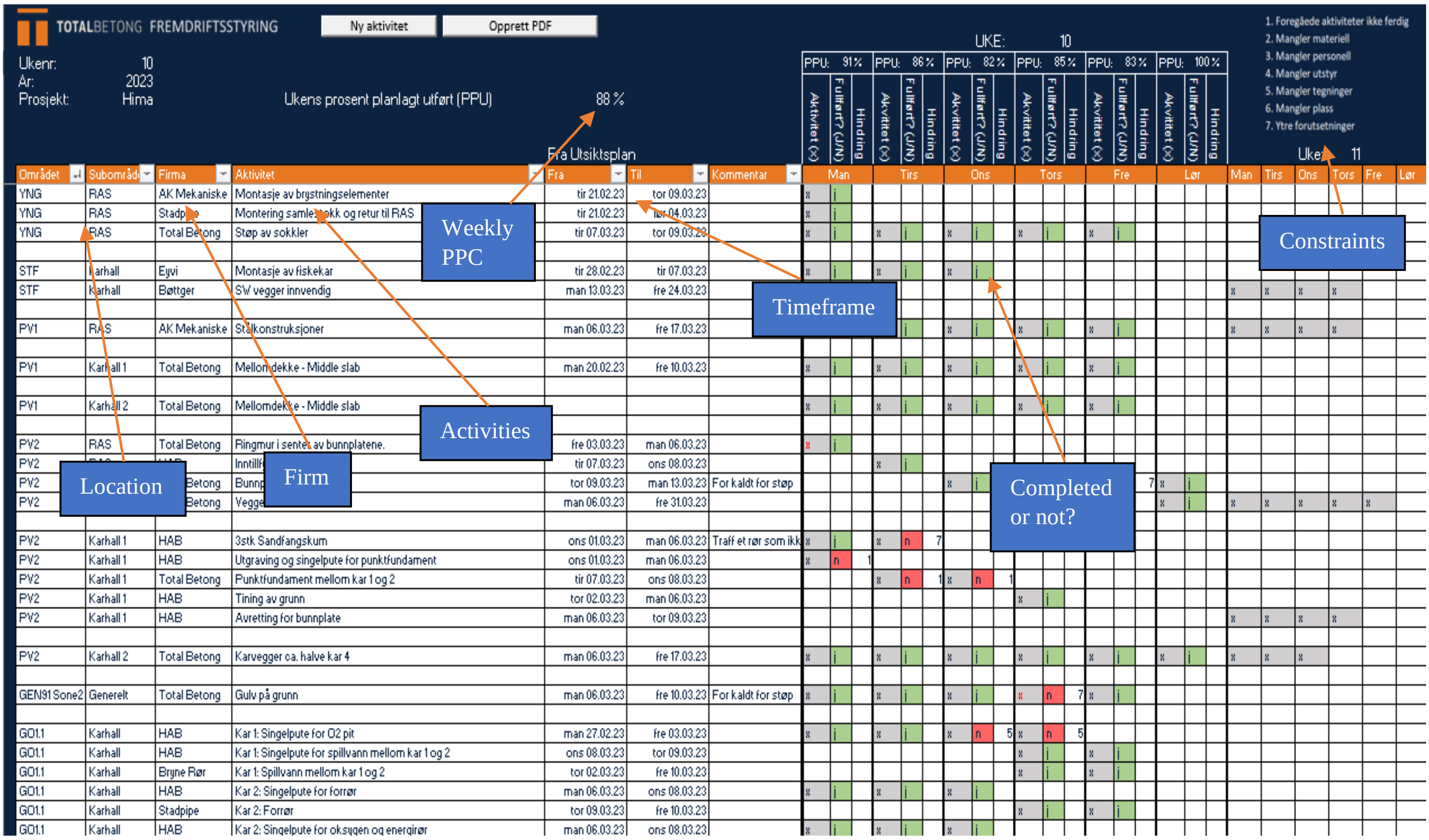


Figure 2: A weekly work plan from Total Betong AS

<u>Percent planned completed (PPC)</u>

PPC is a method used in the Last Planner System to measure the progress and performance of the planning system. This is an important step in creating a culture of continuous improvement. PPC is used most effectively when it is posted somewhere that is available for alle participants to see, this providing an extra incentive to stick to the plans that have been set. It is important that the participants identify each other as reliable which can improve the workflow. PPC measures if WILL matches DID – the activities planned to be carried out with activities that got carried out. If the PPC indicated 100%, then the plan should be planned better, because no plan is perfect. The ideal measurement should be between 80-95%.

2.4 LEAN CONSTRUCTION FOR CONSTRUCTION PROJECTS

Lean Construction concerns project-based production of unique individual products in contrast to “Lean Production” and the “Toyota system” which deals with serial production in stationary industry. A consequence of Lean Construction’s approach is that the question of industrialization does not become a principled strategic choice between cast-in-place production or prefabricated solutions, but a question of the interface between the two (Berg, 2008). What can be produced on the construction site and what can be produced “off-site” and delivered at the right time? To answer this question, factors that affect productivity in such construction projects must be considered.

Table 4: Factors affecting the productivity of parking garage projects

- The **method of construction** affects the productivity of the project.
- A **complex design** with many levels and angles may require more time and effort.
- Poor **site conditions** may require more resources and time for foundation work. Accessibility in terms of bringing in materials and equipment are also critical.
- **Availability of skilled labour and workforce** are deciding factors when choosing between the two building methods for parking garage construction.
- **Weather conditions** can halt the construction work.
- The demand for products in the **market** varies a lot.

These factors should be considered in the design phase and Lean Construction tools and strategies can help to identify and mitigate potential issues that may arise during the construction process, such as delays, quality problems, and cost overruns. By emphasizing early involvement of all stakeholders in the design phase with the Last Planner System techniques and following the value streams of each method, project teams can ensure a shared understanding of the project objectives which can help to make informed decision about which construction method to choose. Experience shows that construction projects that are well planned, where the actors in the different phases of the project coordinate their activities in relation to each other, are more profitable, efficient and meets fewer surprises (Reiersen et al., 2020, p. 12).

2.5 CONCRETE AS A BUILDING MATERIAL

Concrete as a building material is very versatile and the most widely used material. It has long service life, low operating costs and great flexibility in terms of strength, appearance, and geometry, however, it must meet the required standard of strength and durability. Concrete is essentially a mix of cement, sand, gravel, and water (Kontrollrådet, 2022). A chemical reaction occurs between the cement minerals and water – hydration. This hardens the fresh concrete and starts the hardening process. Figure 6 shows the composition of concrete and the proportioning ratio.

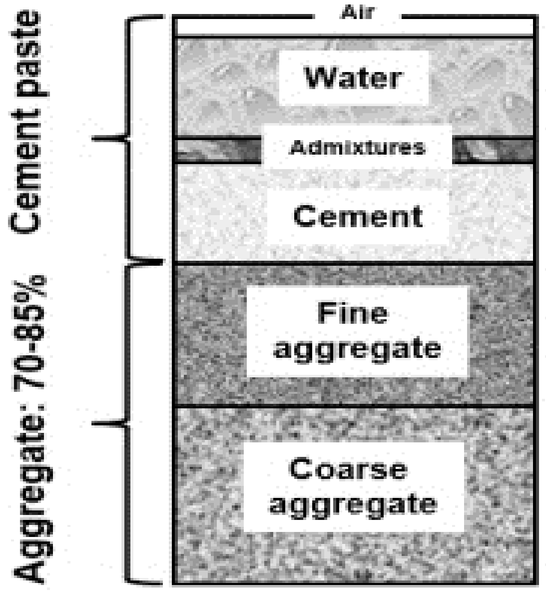


Figure 3: Concrete proportioning (Liu, 2019)

However, cement production, which is the main ingredient of the concrete, has a significant environmental impact which accounts for 7-8% of carbon dioxide emissions annually (SINTEF, 2020). Since the cement in the concrete accounts for around 90% of emissions, the construction industry has come together and is continuously looking for environmentally friendly solutions to produce cement and concrete. One approach is to use alternative fuels instead of fossil fuels in the cement kiln, such as waste materials, biomass (GCCA, 2020). Concrete has, among other things, environmentally friendly properties such as carbon capture and storage. This occurs when pockets of water in the concrete draw CO2 into the wall – a chemical process called carbonation (Kontrollrådet, 2022).

Compared with other building materials, concrete is flexible and offers opportunity to create unique solutions for design. The flexibility gives us an opportunity to increase productivity by optimizing the ways of processing concrete. Concrete has high compressive strength, good durability and can be moulded into a variety of shapes, making it suitable for a wide range of parking garages. Its high thermal mass can also help regulate temperature and reduce cooling and heating costs in buildings. Understanding the customer needs for the specific projects are key when making the concrete, as it is very versatile.

However, there are also some limitations with the building material. Concrete is produced in several ways, but they must satisfy different classes according to the designer and the project management team. Admixtures and the proportioning of the concrete determine several properties such as workability, curing speed, weather conditions etc. Admixtures is one of the most important ingredients in high performance, long-lasting and durable concrete produces today. They are either natural or manufactured chemicals or additives added during mixing stage to enhance or modify specific properties (Sika Group). Also, adding different types of aggregates can modify the strength, workability, and durability of concrete.

The choice of admixtures and different types of aggregates depend on the specific properties required for the project. If the schedule is tight, an accelerator will speed up the process. If the weather is a problem, retarders can be used slow down the setting time of concrete (Sika Group). Admixtures need careful handling as improper use can lead to unwanted results. Additives can make good concrete better, but most usually bad concrete better (Reiersen et al., 2020, p. 41).

2.6 CAST-IN-PLACE CONCRETE

Cast-in-place concrete is the traditional technique that has been utilized for decades. According to Edward Allen and Joseph Iano, cast-in-place concrete can be defined as concrete that is poured into forms on the construction site (Patel, 2019). This method gives the architect or designer more favourable working conditions because concrete may be cast in any shape on any sort of terrain.

Three key sets of activities make up cast-in-place concrete construction:

1. Preparation, erection, and removal of formwork.
2. Preparation and erection of concrete reinforcing systems.
3. Placing, finishing, curing, and patching of concrete.

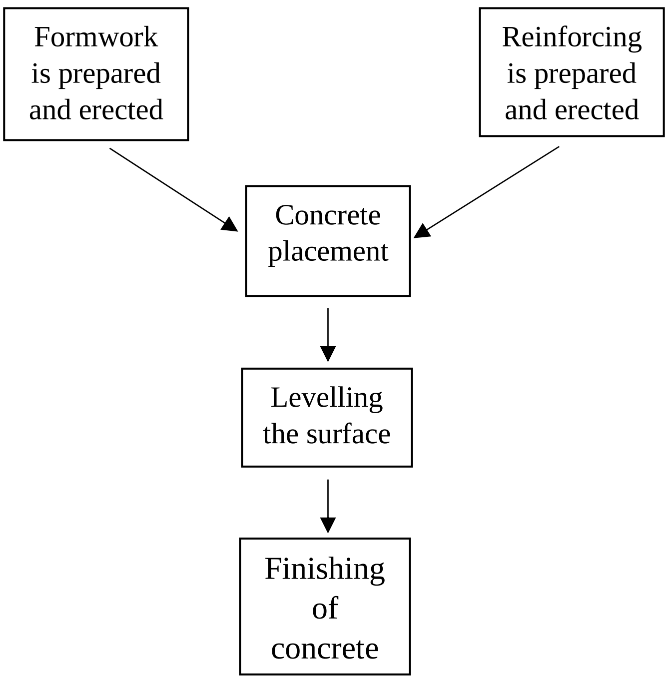


Figure 4: Concrete Process Flow

Preparation of formwork and reinforcing are not independent activities. Sometimes formwork needs to be in place before reinforcing can be erected and vice versa. When everything is in place, wet concrete is placed in the formwork around the reinforcing. Finish off with levelling the concrete surface so that the curing process can start. After a few days, the concrete is strong enough to support its load and the formwork can be removed. Re-shoring can be used in the meantime to support the concrete while other loads are applied over time.

2.6.1 FORMWORK

Throughout the process of working with cast-in-place concrete, numerous factors are crucial such as a good formwork. A formwork is a temporary framework or frame used to shape and support uncured concrete until it hardens. The shape and size of the area to be covered with concrete are determined by the frame. The formwork has a significant influence on the final look of the structure. The frame also defines the bracing and load-bearing component. Hence, careful planning is essential, and the outcome depends on several variables. The height, thickness, temperature, and ground conditions of the concrete construction must be considered (Byggstart).

There are two types of formworks: supporting and load bearing. Supporting formwork holds the new concrete on the frame's sides until it cures. This is typically done on the formwork for a wall or a column. Load-bearing formwork, such as a storey divider, is primarily constructed to withstand fresh concrete until it cures (Forlag). To prevent the formwork from collapsing due to the pressure produced by the concrete, it is important to make sure that the formwork is properly supported.

Using a variety of materials and techniques, the formwork work may likewise be executed in several ways. Traditional formwork, system formwork, climbing formwork, and sliding formwork are the various approaches (Byggstart). Conventional formwork is the traditional method for constructing formwork. It is constructed from wood, plywood, and boards. System formwork is constructed of parts that are built as a kit as shown in Figure 8. This approach is more sustainable and environmentally beneficial since it can be reused. Climbing formwork is an alternative style of construction. This is accomplished by raising the structure after each work, which can be done with or without a crane. The final category is sliding formwork. During the construction process, the formwork is moved smoothly upwards, which is a technique frequently employed to create oil platforms. Often, a mix of the different varieties is required to create the most effective formwork.

Inadequate formwork can result in the construction not satisfying the standards for the building's load-bearing capability. In turn, this might lead to financial pressure and time loss if the project is not completed by the agreed upon date. Poorly performed formwork can potentially result in catastrophic repercussions, leading to the collapse of the structure. Which is also why, the formwork affects the durability of the concrete structure, the total budget, and the duration of the construction project.

Figure 5: System formwork used by Total Betong AS

2.6.2 REINFORCING

Concrete structures cannot withstand a lot of loads without suitable reinforcement. Almost all structural members are subjected to tension for some degree. For example, beams must resist bending, and columns must resist buckling. Concrete must be reinforced as it has very poor tensile strength, especially large spans (Redaksjonen, 2023). This is done by assembling steel bars into cages or mats and placed into the formwork where the concrete should be placed. Steel rebars have good tensile and moderate ductility, and therefore complements concrete’s disadvantages. Proper placement and sufficient spacing of the reinforcing bars within the concrete are also necessary to achieve the desired strength and durability of the concrete structure. This helps with prevention of cracking of the concrete under load (MerutConstruction, 2021).

The process is very similar to the process of preparing and erecting formwork. They can come in prefabricated reinforcing elements, or in pieces which requires preparation. Usually, the steel bars are delivered to a site already cut and bent into the required shapes, but if not, sufficient time goes to preparing the reinforcement. Ironworkers are responsible for reinforcing preparation activities.

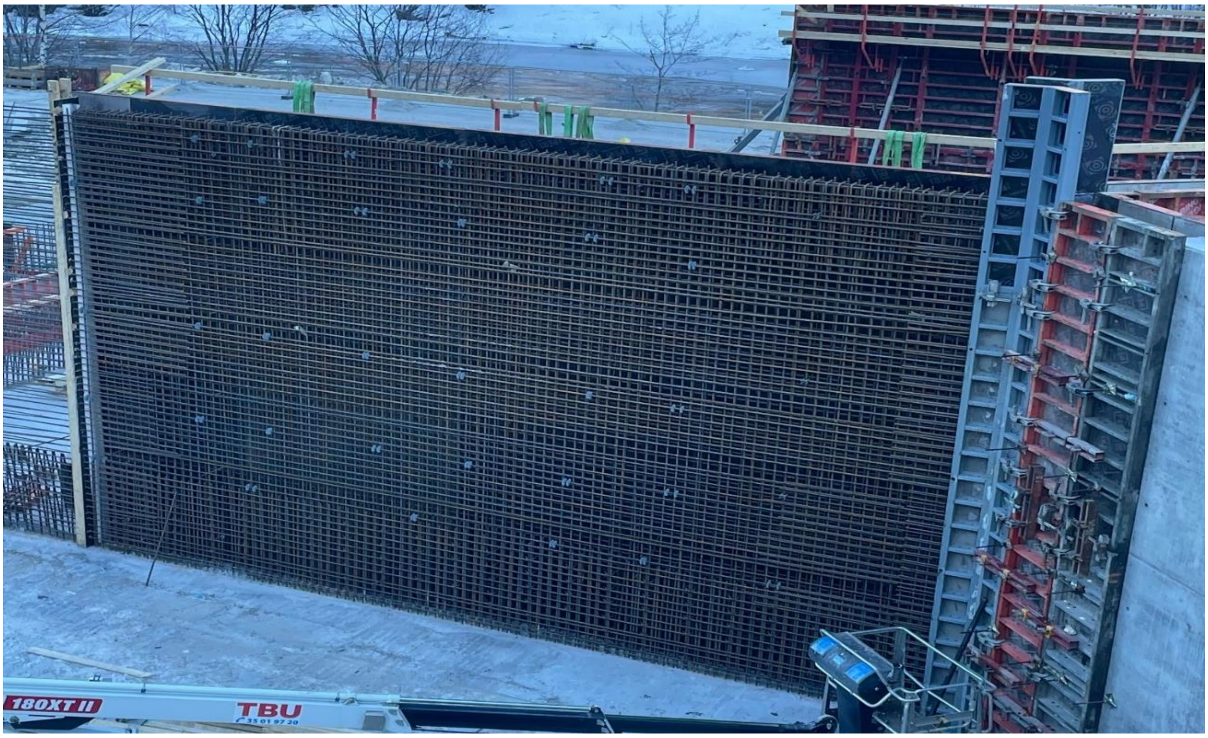


Figure 6: Steel Reinforcement Inside a Formwork

2.6.3 CONCRETE PLACEMENT

The next stage is to pour the concrete once the formwork has been set (Christensen, 2018). The casting concrete is mixed at the concrete station and brought to the building site by concrete truck. The concrete truck is a unique vehicle that carries a rotating tank. Fresh concrete is regularly spun and mixed in that tank to ensure that the ready-mixed concrete does not separate. The concrete mix separates because the stones and gravel in the concrete mix sink, and the water, which is lighter, floats up (Brørs, 2019). To avoid this, the tank rotates continuously until the vehicle arrives at the construction site.

As the concrete truck carrying ready-mixed concrete arrives at the building site, numerous procedures must be followed. First, the concrete must be examined for receipt. A check is done here to ensure that the amount and consistency of the concrete are as planned. A sample taken with a sink cone is used to determine the consistency, usually with a slum test. The sinking cone is filled with fresh concrete, and the cone is lifted, leaving the concrete behind. Then, using a measuring stick, determine how much the concrete sinks (Brørs, 2019). The sinking distance shows the concrete's consistency. The longer the distance is, the more liquid it is.

There are numerous methods for transporting new concrete for casting on the construction site. If the formwork is near to the concrete truck, it can be done via a channel stretched from the truck's back. The concrete flows from the chute onto the formwork. In general, the formwork is not always near to the vehicle. Then a pump is used. By pouring concrete continually, the pump goes everywhere and is efficient (TheConstructionWiki, 2021). A concrete tub can also be used for this procedure. A concrete tub is a big container with a hatch at the bottom that is raised above the formwork by a construction crane before the concrete pours over it. A wheelbarrow is the final method of transporting concrete for casting. Wheelbarrows are only used for small-scale casting projects.

Figure 7: Pump truck and concrete truck

The consistency of the concrete after it has been filled into the formwork is also a significant consideration in the casting process. The concrete is vibrated with a vibrator to prevent voids from forming in the concrete after the formwork is removed (Brørs, 2019). If it is not thoroughly vibrated, air bubbles will form in the concrete and emerge on the surface of the fully hardened concrete. Therefore, before the formwork can be removed, it must be vibrated.

Levelling is the final step before the concrete hardens and the casting of concrete is completed. Levelling is a technique used on the surface of concrete. The surface must be flat and smooth. The final step in the casting process is to allow the concrete to harden before removing the formwork.

2.6.4 CURING AND FINISHING OF CONCRETE

When the formwork has been filled with ready-mixed concrete, and the casting has been completed, the concrete construction is not necessarily complete. It is essential to finish off with surface treatment once it is hardened. This is true regardless of the time the concrete is made. Concrete preparation decreases the probability of cracking and has a significant impact on the long-term qualities of the concrete.

An excellent finish will have an impact on the concrete and the building in various ways. First and foremost, the concrete's strength will be greatly improved. The construction is going to have sufficient durability. This indicates that the construction will have the expected durability without the need for costly maintenance. The treatment will protect the concrete not only from all forms of weather, such as wind, temperature, and frost, but also from vibration, impact, and damage. Finishing will help ensure that the concrete retains a smooth and fine surface with proper follow-up (Kontrollrådet, 2021).

Using a curing membrane soon after casting is an excellent technique to finish the concrete. This is accomplished using a low-pressure spray that forms a visible film over the concrete, protecting it from drying out and water loss. The curing membrane will assist the curing process in the days following casting.

As already mentioned, casting concrete is a critical step in which a lot may go wrong both before and after casting. It is critical to cover the concrete surface with plastic once it has been cast. The surface should be covered for a variety of reasons. Moisture can evaporate fast in the sun if freshly poured concrete is left with an exposed surface in the heat. This will crack the concrete and weaken the curing process. Cracking can occur relatively fast. This may happen everywhere, not just in the heat. If the concrete is left exposed in the cold, the dry air can cause it to dry out and crack. The plastic will help the concrete in maintaining an even surface while also ensuring that the hardening process is optimized. As a result, it is recommended that the plastic remain left on for at least one or two weeks.

The concrete's fallen must be dust-bound once it has been poured and properly cured. Dust binding the surface prevents the spread of cement dust, reducing dust accumulation on the concrete. Without dust, the surface is easier to clean, and the concrete has better chemical resistance, which prevents cracking or volume changes (Norcem).

2.7 PREFABRICATION OF CONCRETE ELEMENTS

Precast concrete are concrete elements that are produced in a factory, which are later transported for installation on the construction site. The elements are cast in different shapes, reinforced, and cured in a controlled and indoor production facility. The elements come in many different forms and are produced in large quantities today. The main characteristics include high construction speed, less waste, high safety and more control of cost and quality. Precast concrete elements have a wide range of applications and are especially suitable for parking garages, office buildings, schools, and large premises where long spans are required.

2.7.1 PRODUCTION PROCESS

There are different ways to produce off-site concrete elements and it depends on the number of identical elements to be made. Such factories will usually resort to standardized products such as hollow-core slabs so that they can produce similar products in larger volumes. Traditional formwork materials wood and veneer are used for smaller productions. For larger production, it is better to use steel moulds, as they are adjustable. Adjustable formworks are particularly profitable for beams, girders and columns that come in different shapes and dimensions. Larger elements such as walls, retaining walls, covering and facade elements are cast horizontally in steel frames with either veneer or steel at the bottom. There are also built-in vibrators in the moulds that distribute the concrete evenly and reduces labour work.

In the same way as in the process of cast-in-place concrete, reinforcement is perhaps the most important component that must be in place before the concrete pouring. The elements can either be tension-reinforced or slack-reinforced. Slack-reinforced elements are reinforced in the same way as with cast-in-place concrete, where the rebar is tied into the form. Tension reinforcement of elements, on the other hand, is when a rope attached to the ends of the forms is tensioned with a jack. The load the elements must withstand determines how much the rope must be tensioned. After the hardening process, tension-reinforced elements must be gradually relaxed using hydraulics or by cutting carefully (Reiersen et al., 2020, p. 39)

2.7.2 TRANSPORTATION AND ASSEMBLY

The assembly sequence that makes the most sense should be already planned at the offer stage. Factors that play a role are space for arrival and storage, access roads, and not least ensuring that the building is table during assembly (Reiersen et al., 2020, p. 49). The progress plan should be drawn up using the Last Planner System principles as early as possible. Any risk moments and safety requirements must be discussed here as assembly of prefabricated elements require a good HSE plan.

Transportation

Typically, prefabricated concrete elements are transported to the construction site using trucks or trailers, but rail transport and boats are also relevant for longer distances (Reiersen et al., 2020, p. 52). The transportation process needs careful planning to ensure elements arrive in good condition on time. This includes considering the size and weight of the elements, and planning the routes to avoid low bridges, narrow roads, or other obstacles that might damage the elements. It is common to use A-frames when transporting on trucks, or with the elements placed one above the other.

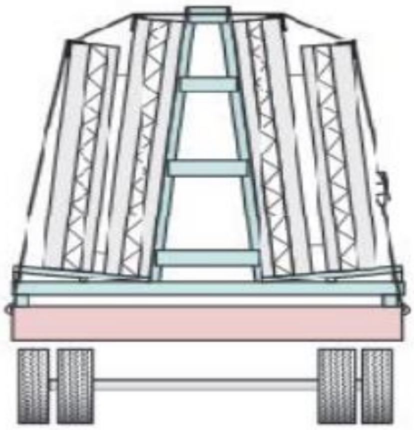


Figure 8: Transportation of elements in A-frame (Reiersen et al., 2020, p. 72)

To make assembly on the construction site more efficient, the elements should be arranged with the elements that should be assembled first is at the top of the load. The center of gravity should also be considered, i.e., the heaviest elements should be at the bottom (Reiersen et al., 2020, p. 71).

Handling and storage

Driving inside the construction site must be carried out in a safe manner. Receipt control of the load is important according to the order, to ensure that the load has not been damaged during transport and the elements are ready for unloading as soon as the inception is done. Unloading is carried out in accordance with the regulations, the weight of the load and other safety rules that have been laid down beforehand (Reiersen et al., 2020, p. 72). The elements must also be stored in a secure location where they are easily accessible during the assembly process. The ideal situation is to lift the elements straight from the truck to their final location in the building, as the least possible intermediate storage is desirable. This is based on the Just-in-Time principle.

Assembly

Assembly is based on carefully thought-out plan from the project team and constructor. This means that all materials and specialized equipment are in place, including cranes and scaffolding (Reiersen et al., 2020). Crane and transport are usually included in a total delivery by element suppliers. Necessary markings and positions must be measured and marked before the elements are lifted. After, disconnection from the crane must not take place until the elements have been securely fixed with the rest of the building. Fixing methods can be glued fixing, sleeve foundation or with foot plate (Reiersen et al., 2020, pp. 91-93).

Almost all elements are sealed after assembly. The purpose is to ensure rain, wind and steam sealing with good heat and sound insulation. Sealant and sealing strips are used, but elements such as hollow-core slabs require concrete topping to achieve a horizontal surface (Vinje, 2018). Quality control is important in all phases from transport to final assembly.

2.7.3 COMMON ELEMENT TYPES

Concrete elements come in many forms and can be divided into load-bearing parts for construction and concrete products. Stock products such as railway piles, roof tiles and slabs are concrete products with standard dimensions that make it beneficial to produce in series. Load-bearing construction parts, on the other hand, are made-to-order items that are tailored for each project. The most usual load-bearing elements are double tees and hollow-core slabs.

Hollow-core slabs

Hollow-core slabs are precast concrete planks used in big apartment buildings, schools and as floor dividers in industrial buildings. They are lightweight, easy to install and give parking structures a flat surface and durability. They are cast by extrusion or in sliding formwork in large lengths with steel underneath which gives the elements a smooth surface (Betongelementforeningen, 2010). The concrete slab is extended to the full length with hollowed-out tunnels inside of it which can accommodate for various openings, such as ventilation and lighting. Recommended spans will vary according to conditions such as cross-section size and end anchorage.

Double-tee slabs

DT-elements are used as slabs in car parks due to their low dead load and high load capacity (Betongelementforeningen, 2010, p. 109). They can cover large spans and therefore appropriate for parking garages with a lot of parking spaces. Due to the unique shape and long spans, the need for intermediate columns is reduced. DT-elements and hollow-core slabs are cast with prestressed reinforcement. Any recesses can be placed in between the ribs.

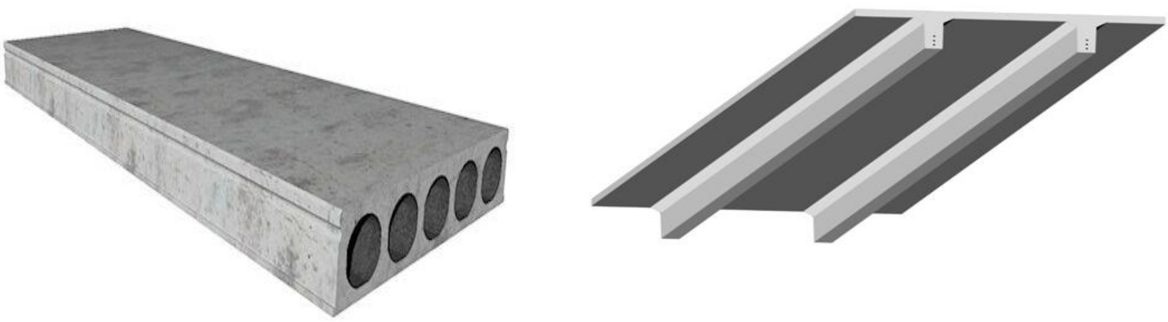


Figure 9: Hollow-Core slab and Double-tee slab

Other elements

Precast beams and columns are designed to support the slab above and can be used in conjunction with DT-elements and hollow-core slabs to create a complete parking structure. They can be cast with various textures and are often designed to fit together the elements in a specific way, which allows for efficient assembly on site. Walls can be produced with and without insulation. Stair and elevator shafts can also be prefabricated but requires great accuracy as they are customized for the specific requirements of different projects.

2.7.4 PREFABRICATION AND LEAN

Prefabricated elements align well with Lean principles, as the importance of minimizing waste, standardization, and maximizing productivity are emphasized. Prefabrication provides the opportunity to move large parts of value creation away from the construction site and into an environment where the conditions are better suited for production. The process of prefabrication is related to the "Toyota system" which deals with serial production in stationary industry. The traditional way of casting on site is being challenged today with concrete elements or hybrid systems where some concrete elements are included. Building with concrete elements represents an economical and time-saving construction method, while at the same time reducing the carbon footprint by more standardized production.

Standardization

Andrew Loo (2023) defines standardization as *«…the process of creating protocols to guide the creation of a good or service based on the consensus of all the relevant parties in the industry».*

Standardization of products ensures a systematized and integrated process that can significantly reduce waste and improve quality. Building components have multiple elements and inputs that have the potential for repetition, and prefabrication is mentioned as an approach to increased standardization (Egan, 1998). Egan points to several studies from the US and Scandinavia where 10% of materials end up as waste and up to 80% of the inputs in a project are repetitive. The close connection between standardization and prefabrication facilitates the production of elements that can be used across projects which give the opportunities to produce in large series.

Such processes will lead to major operating benefits, precisely because of the effects of repetition. However, it requires sufficient collaboration of stakeholders, project team, and suppliers. In relation to housing projects, standardization can be problematic as there are different preferences amongst the customers, mainly because standardization does not seem individually adapted, for that reason, less attractive for the customer. For parking garages, standardizing the design of parking spaces is easier and can help producing standardized products.

Table 5: Benefits from Increased Standardization

- Shorter construction time due to prefabrication
- Less need for highly skilled workers
- Better quality due to production in controlled environment
- Fewer interfaces
- Fewer problems with tolerances
- Overall reduction in production costs in the entire value chain
- Increased predictability
- More effective research and development

Good logistics with Just-in-Time

When it comes to prefabrication and industrialization, good logistics are essential. There must be set clear plans for inventory management, how the elements are to be transported and how they are handled on the construction site (Berg, 2008). Additional lead times and costs can be avoided with standardized processes, especially in inventory management. This requires an experienced management team but ensures a smooth flow of assembly.

Just-in-Time (JIT) is a strategy that emphasizes the delivery of materials, products, and other services exactly when they are needed with the right quantity and quality (Pihl, 2022). The core principle of this Lean management strategy is to reduce inventory and lead times. Excess inventory and risk of overproduction can be reduced with coordination of production with customer demand. This can be achieved with a standardization of production, and pull production where production is started based on forecasted demand. The Last Planner System is a planning and control methodology but some of its principles, with some modifications, can also be applied to manufacturing processes, mainly production control, collaborative planning, and a culture of continuous improvement.

2.8 CHARACTERISTICS OF PARKING GARAGES

Parking garages are defined as buildings designed to provide parking spaces for vehicles. The overall design principal to keep in mind is that it is for the people. They can be integrated into larger buildings or act as standalone structures. Even though parking garages are classified and constructed as buildings, they are in some way unique and compared with bridges with multiple decks. Parking garages are subjected to moving loads from automobile traffic and the roof level being exposed to weather in the same way as a bridge deck (Force, 2010, p.

31). Usually, they are open-air structures where the entire structure is subjected to surrounding weather conditions. These factors require special attention to durability to ensure long-term sustainability performance.

A parking garage basically only needs free surfaces, large spans, and good ceiling height, but we have still further expectations of what should be included in a parking space. It must be designed to support heavy loads from the weight of vehicles which distinguishes them from other buildings. This requires a good structural system and careful consideration of materials used. The design should aim to maximize number of parking spaces and to be accessible to all users, including those with disabilities. The decisions made are often based on owner and design team preference according to the allocated budget and schedule.

Design and construction of parking garages must meet certain standards which can vary depending on local building codes and regulations. The requirements for height and area ventilations, safety, and lighting also depend on building codes and other standards.

2.9 CAST-IN-PLACE VS. PRECAST CONCRETE

Today, it is possible to build most parking garages and buildings generally with both cast-in-place concrete and precast concrete elements. But the choice is dependent on critical factors, and it is important to have in mind that every garage is susceptible to deterioration. Time and space are therefore the two conditions that make the biggest impact on the choice of solution, not building type. Expenses are obviously another factor you need to pay some respect to but rarely, the material costs determine the solution, it is more the overhead expenses imposed over time. While both methods have their advantages and disadvantages, a comparison can help stakeholders make a more informed decision.

In addition to the literature available online, the data was collected through interviews and personal communication with employees in contractor company Total Betong AS, as well as the precast supplier Block Berge Bygg AS. Table 6 and 7 show the advantages and disadvantages. Lastly, Table 8 shows the comparison of price for prefabricated and cast-in-place slabs, walls, and columns. Price of elements are estimations with included design, manufacturing, transportation within a 50km radius of the factory, and installation.

Table 6: Advantages and disadvantages of cast-in-place concrete

Cast-in-place concrete	
Advantages	**Disadvantages**
▪ Flexibility in design allows for adjustments during construction. ▪ Adaptable and easier to produce hidden solutions. ▪ Long lifespan and stable buildings. ▪ Fewer sealant joints due to monolithic construction ▪ Air- and waterproof. ▪ Lower maintenance cost.	▪ Longer construction time on site. ▪ Potential quality issues due to on-site variables, such as weather conditions and workmanship. ▪ Requires a lot of storage space and often a tower crane. ▪ Requires a lot of labour and highly skilled/experiences employees. ▪ May require heating or covering. ▪ Safety of workers in risk.

Table 7: Advantages and disadvantages of precast concrete

Precast concrete elements	
Advantages	**Disadvantages**
▪ Requires less time on site. ▪ Large spans with prestressed slabs to create open and efficient layouts. ▪ Cost advantage of repetition in producing series of elements. ▪ Quality control under ideal conditions. ▪ Accelerated curing. ▪ Adaptable to winter construction. ▪ Potential for waste reduction and reuse. ▪ Requires less skilled labours.	▪ Planning must be completed before production and requires highly skilled contractors. ▪ Not so flexible and adaptable to changes during production. ▪ More propensity for leaking at the joints. ▪ May require additional concrete topping. ▪ Very market-dependent ▪ Higher maintenance cost for sealants

Table 8: Comparison of price

	Cast-in-place	Prefabricated elements
Slab	1258 kr/m²	950 kr/m²
- Formwork	710 kr/m²	
- Reinforcement	22,5 kr/kg	
- Concrete pour	2080 kr/m3	
Wall	2115 kr/m²	2500 kr/m²
- Formwork	408 kr/m²	
- Reinforcement	22,1 kr/kg	
- Concrete pour	2136 kr/m3	
Columns	5000 kr/m	6000 kr/m
- Formwork	624 kr/m²	
- Reinforcement	22,1 kr/kg	
- Concrete pour	2136 kr/m3	

2.10 PREVIOUS STUDIES

There is already a lot of literature on concrete and the science of concrete as a material. There is also a lot of literature and information about the advantages and disadvantages of cast-in-place concrete and prefabricated concrete elements, however, the choice of solution for specific projects is mostly found in case studies. "Betongelementforeningen" has published a book with several volumes that covers many aspects of the two construction methods but general literature on the choice of solution is very limited, which makes this master's thesis an experiential paper based on input and opinions from experts in the industry.

There is still limitations and gaps in previous studies that this research aims to address. Mostly they are studied in terms of costs and time but a deeper understanding of other qualitative factors such as construction complexity, HSE, quality, and flexibility may also be important in making the choice between the two methods. There is an enormous amount of experience-based knowledge, but it is rarely documented. Analytical Hierarchy Process-method (AHP), which is explained in the following chapter, has been selected to address the limitations and gaps by comprehensively compare the two constructions method based on multiple criteria.

Chapter 3: Methodology

This chapter contains the definition of different research designs and research approaches. In the subpart of this chapter, the analytical method will be presented following a presentation of the reference projects provided by the company in collaboration.

3.1 RESEARCH METHODOLOGY

There are several methods for conducting research, both qualitative and quantitative. Both methods have their advantages and disadvantages, but the scope of the research objective were decisive in our choice of method.

Table 9: Definitions of quantitative and qualitative methods (Dalland, 2020)

Qualitative methods	Aims to capture opinions and experiences that cannot be quantified or measured. Its purpose is to provide an understanding of a process. It is suitable for providing answers to what, how, and why questions.
Quantitative methods	Aims to convert information into measurable units. Its purpose is to quantify variables of a unit or process. It is suitable for providing answers to how many/how much questions.

The aim is to uncover linkages and inconsistencies when comparing cast-in-place concrete versus precast elements for parking garages under apartment blocks. According to (Dalland, 2020), it is beneficial to use many strategies when working on such an assignment. The quality of the research will increase as more methods are used. The methods used are mostly qualitative based on literature, case-studies, and conversations with relevant people. The cases covered in the thesis have been subject to qualitative assessments in form of time and cost estimates, but the only method that can be described as quantitative is the Analytic Hierarchy Process (AHP). The methods used will be described in detail in the next sections.

The quality of the research will be determined by three factors: reliability, validity, and timeliness. Timeliness is critical when working with an issue that is actively explored from multiple points of view. In other words, how useful the data is for future research. The accuracy and reliability of the information will determine its trustworthiness. Validity is described as the amount of information that relates to the objective that is being investigated. It is essential that the conclusions drawn from the research become clear and understandable to other researchers and readers (Leegard, 2017).

Distinction between inductive and deductive research should also be considered. Inductive research develops theories based on studies, whereas deductive research tests theories against reality. Both are approaches are utilized deliberately as well as unintentionally. In other words, neither approach can be selected over the other because both are necessary to answer a research objective with such wide scope. However, the chosen perspective has an impact on how an issue is formulated for assessment (Sander, 2022b).

Figure 10: Inductive and deductive approach (Mike, 2021)

Both inductive and deductive approaches have advantages and disadvantages. The inductive technique is distinguished by the idea of perceptions formed in the past are utilized to predict the future. This indicates that rules, concepts, and hypotheses have been developed based on a restricted number of observations. This approach has a lot of flexibility, but the problems it solves tend to be loosely defined with a lot of uncertainty. When adopting the deductive technique, however, the theories are separated into different hypotheses, that are then examined. This strategy has fewer uncertainties, gives greater clarity, usually requires less time, and doesn’t require as much expertise. As a result, the deductive technique is commonly, the preferred approach.

The inductive approach was largely employed in this thesis, with a modest contribution of the deductive research method. The effort is enormous since it entails gathering information from four reference projects that constitute the case. Two of the three projects were already completed, preventing inspections and measurements during the construction process. As a result, this became a task that builds on previously established ideas and then evaluates these through choices and real-world experience. Although no physical tests have been performed, it still involves physical field observations as well as interactions with specialists who build on previously acquired knowledge. Hence, the method of choice required a procedure with a high degree of flexibility (Sander, 2022b).

3.1.1 LITERATURE STUDY

A literature study is a comprehensive search approach for researching the existing literature around a topic. It entails conducting a systematic and analytical search for information, as well as comparing the information discovered with other sources. A review of the literature must be done properly and methodically as it establishes the foundation for the rest of the thesis.

There are two types of methods of studying literature: systematic and conventional (UiO). The goal of the conventional technique is to get a wide understanding and overview of the issue. The purpose of this strategy is to get an overall picture of the subject. In terms of source criticism, the author's overall judgment is stressed in order to determine if the source is reliable and relevant. The purpose of the systematic method is to narrowly focus on a specific, well-defined research objective. This method is severe, especially when it comes to source critique, where sources are checked for quality before being used. In this thesis, a systematic literature study is used.

Like most other methodologies, a literature study has also drawbacks. A good theoretical perspective is gained because of the huge selection where information can be rapidly obtained. The drawbacks of studying literature include a restricted and selective selection of relevant research. Another downsight might be the misconception of the material if several sources with the same objective shows diverse views. This will affect the judgment of the author in relation to source critique.

Due to the use of systematic literature review, it is time-consuming to become conversant with the all the found literature. As a result, the source selection should include a fair judgment of the sources with a good balance between articles, books, journals, research reports, and other forms of literature as the primary sources for information.

3.1.2 CASE STUDIES

«*A case study is an empirical method that investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident*» (Yin, 2018, p. 45)

This means that the conclusions are based on data and scientific research of the particular case, but they cannot be generalized. Case studies have a flexible research design, which means that various research designs are combined throughout the process to analyze problem-relevant data (Sander, 2022a).

Due to the lack of theory within the subject, it has been relevant to make use of reference projects, in the form of case studies, to gain access to data and experiences. According to Yin (2018), when it comes to multiple case studies, a strategy should be developed for what the author should document and what they should not. In this manner, it is possible to compare the various cases and results in a systematic manner. The case studies in this thesis examine two completed parking garages and one under-construction parking garage. The data material was based on project documents. In addition, documents such as contracts, tender documents, drawings, and meeting minutes were available.

Field observations played a crucial role in the data collection process for the case studies, as they provide valuable insights into the construction process, site conditions, and worker behaviour. In addition, it also helped to clarify any misunderstandings that may have arisen from the project specifications. Field observations are a qualitative data collection method that involves observing and documenting phenomena in a natural setting (Patton, 2014). Overall, field observations provided a rich source of data that complemented the other data collection methods used in the study.

Table 10: Field observations of given reference projects

Project name	Location	Building system
Skadberg Alle	Sola, Rogaland	Cast-in-place concrete
Mosvannet Park	Stavanger, Rogaland	Combination of cast-in-place and elements
Kvernaland Torg	Kvernaland, Rogaland	Combination of cast-in-place and elements
Bykronen	Stavanger, Rogaland	Cast-in-place concrete (under construction)

A detailed and systematic review of the literature was conducted prior to the preparation of the research study. The focus has been on structure and ensuring that the instances accurately represent the actual conditions. As a result, the selection of databases and literature is crucial to completion of this assignment. In addition to preserving neutrality and avoiding confirming one's own hypotheses, the entire procedure ensures that the task is conducted without bias.

3.1.3 INTERVIEW PROCESS

Interviews were useful to gather insight and in-depth knowledge regarding incidents, ideas, evaluations, debates, choices, measures, or developments that are important to the research objective, mainly the case studies (Difi, 2022). It is about encouraging the individual being questioned to supply pertinent information that provides the interviewer with new knowledge that verifies or disproves ambiguities about a topic.

There are different methods to conduct an interview, and it is considered a good method especially for qualitative studies where different perspectives and experiences are relevant. An interview can be structured or unstructured, qualitative, or quantitative. Qualitative interviews usually rely on an interview guide that has been assigned beforehand, while quantitative interview methods are based on questionnaires with predefined questions and answer alternatives. The quantitative methods are structured interviews while qualitative methods are unstructured (Sander, 2020).

For this thesis, mainly qualitative interview methods have been used, but specific quantitative information has also been requested. An interview guide was sent to the individuals being interviewed in advance so that they have an opportunity to prepare well and find necessary figures and data. In this way, the validity and reliability of the interviews increase, and it also makes the participants and interviewer feel more secure. In addition, the interview becomes a fluid dialogue where relevant topics are discussed and clarified for the interviewer. This can be classified as a semi-structured interview, and the method was deemed most suitable for the thesis.

This strategy has both advantages as well as disadvantages. The disadvantages of the semi-structured interview approach include that the questions asked might appear impersonal due to the planned format. As a result, larger expectations will be put on interviews, requiring that the interviewer be well prepared so that the dialogue does not appear forced. The benefit, on the other hand, is that the accuracy of the evaluation given after the interview is high, and the interviewer will be left with more knowledge than anticipated. Another advantage is that since the questions are identical, it is easy to compare the replies from various informants (Academicwork, 2023).

While selecting interviewees in semi-structured interview methods, a theoretical or strategic decision is taken. While selecting interview subjects for the thesis, a strategic selection was taken based on individuals who had special responsibilities in connection with the implementation of the projects under consideration. As a result, project managers and facility managers who had overall responsibility for the projects were the main targets. Other relevant interviewees included prefabrication suppliers, estimator, and other actors throughout the value chain (see Table 11). Their perspective and experience are valuable towards the problem.

Table 11: Overview of the interviewees

Name	Company	Years in the industry	Role
Kurt Helland	Total Betong AS	25	CEO Project manager
Berit Maudal	Total Betong AS	9	Estimator
Khoi Dinh Nguyen	Veidekke Prefab	40	Project manager Sales manager
Fredrik Knutsen	Total Betong AS	3	Facility manager
Tor Magne Ramstad	Total Betong AS	40	Concrete manager Project manager

3.2 SELECTION OF REFERENCE PROJECTS

In Total Betong AS and subsidiaries, parking basements are set up using various execution methods. The building materials are concrete, but the products can be cast-in-place, prefabricated elements, or a hybrid solution of both. The choice of method depends on the specific projects and is regulated by various influencing factors such as budget, quality, schedule, project complexity, market, and not least HSE.

As previously mentioned, case studies have been used to answer the research questions and objectives of the study. The selection criteria for the reference projects were dependent on similarities in purpose, construction method and availability of data. Although four different parking garage projects were given as reference projects (see Table 10), one of them were excluded for further study due to similarities in building systems. They are all housing projects but the focus for this thesis will be on parking garages underneath the apartment blocks. Two of the projects have been completed and the last one is underway during the first quarter of 2023. By including reference projects that use both cast-in-place and precast elements, we were able to conduct a more comprehensive and rigorous analysis, enhancing the validity of our research.

Skadberg Allé

Figure 11: Skadberg Allé (Total Betong, 2021)

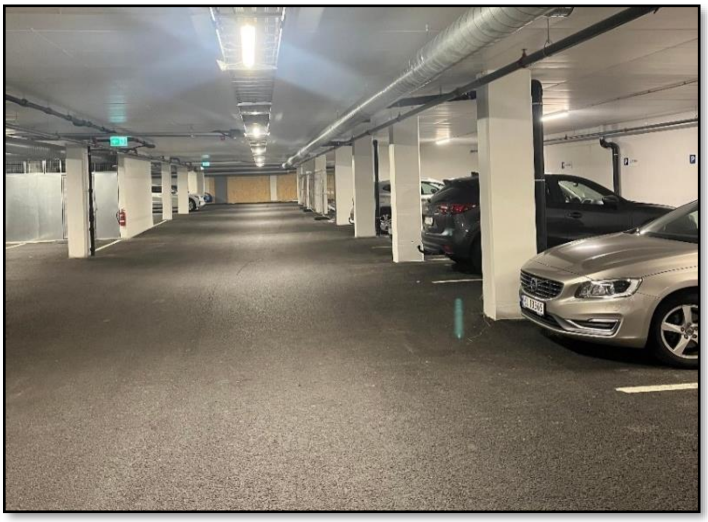


Figure 12: Skadberg Allé parking garage

Table 12: Key information on Skadberg Alle parking garages

Localization:	Sola, Rogaland
Owner:	Bygg-Service AS
Construction time:	June 2020 – March 2022
Total cost:	NOK 12,9 million
Area:	4000 m2
Contracting method:	Subcontractor on concrete work
Construction method:	Hybrid of cast-in-place and precast elements

In the first phase of this project, a parking basement with a cover of approximately 3,000m2 was cast-in-place. According to the project manager, the choice of cast-in-place concrete was driven by the owner's requirement for quality. The project manager believed that precast elements could have been chosen if the schedule was tight, but since Total Betong was a subcontractor with a good timeframe to complete the work, the choice naturally fell on cast-in-place concrete. After covering the parking basement, walls and covering were put in place for an apartment block and terraced houses. The diversity of casting the whole parking garage provided us with the opportunity to analyse in greater depth.

Mosvannet Park

Figure 13: Mosvannet Park (Betong, 2020)

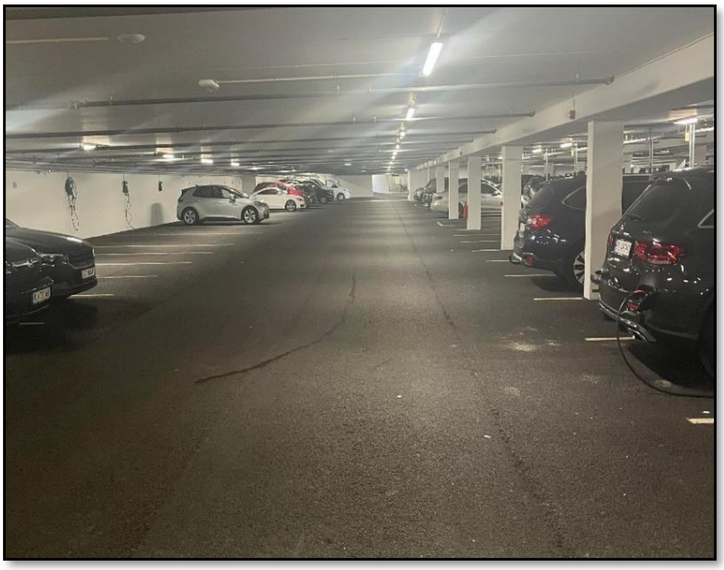


Figure 14: Mosvannet Park parking garage

Table 13: Key information on Mosvannet Park parking garages

Localization:	Stavanger, Rogaland
Owner:	Utvikling AS
Construction time:	April 2020 – November 2022
Total cost:	NOK 11,4 million
Area:	3890 m2
Contracting method:	Turnkey contract
Construction method:	Hybrid of cast-in-place and precast elements

According to the concrete manager for the project, quality and parking utilization were high on the list of owner's requirements. The timeframe for the parking garage was slightly shorter than for the previous project due to the fact that the apartment buildings were divided into two stages and had more apartments. This was the main reason for choosing mostly precast concrete elements. By using elements, it is possible to create long spans that provide better design and parking utilization (see Figure 17).

Production went fairly smoothly according to plan, but there were some problems with the topping where it had to be repeated several times due to poor sealing.

Bykronen

Figure 15: 3D concept of Bykronen (Bykronen)

Table 14: Key information on Bykronen parking garage

Localization:	Stavanger, Rogaland
Owner:	Utvikling AS
Construction time:	February 2023 – Estimated August 2025
Total cost:	NOK 5,8 million
Area:	2560 m2
Contracting method:	Turnkey contract
Construction method:	Cast-in-place concrete

This project is under construction, and thus gives us the chance to see it in practice and have conversations with concrete- and project managers about the existing methods being used. From the field observations, it was possible to see how the excavation process was underway, and the visit to the construction office was useful in terms of how the collaboration worked between the departments. Lean techniques were used for planning and progress with pull-planning and Last Planner system principles.

According to the project manager, the decision to cast the parking garage on site was based on the need for high-quality construction and flexibility due to the topography and site conditions. There is limited space for a mobile crane, making it more convenient to use a tower crane. Despite the tight schedule, the choice was made to cast the garage in place. In the further analysis, this project will be used to see if the decision can be challenged with either precast concrete elements or a hybrid solution of both. Analytic Hierarchy Process (AHP) will be used, and the next subchapter will give a detailed description of the process.

3.3 ANALYSIS METHODOLOGY

Analytic Hierarchy Process, abbreviated as AHP, is a multi-criteria decision-making approach developed by the American mathematician, Thomas L. Saaty, in 1980 (Mæhlum, 2022). It is most suitable for fuzzy problems with multiple criteria and alternatives, especially in areas of planning and management.

The AHP method was adopted in this study as it delivers an objective, quantitative analysis of ineluctable subjective preferences of a group of decision makers. The AHP method allows decision-makers to weigh the relative importance of different criteria, based on their expertise and experience. This enables them to make an informed and well-justified decision that considers all relevant factors. AHP software, like the Expert Choice, is often used to calculate these scores.

In addition, it recognizes that humans are prone to making mistakes in decision-making, especially when there are multiple options and deciding factors (TransparentChoice, 2023). When people are faced with a decision between two or more possibilities, gut instinct or biased choice will play a significant role. This is prevented by the AHP method. The decision will be fair since the alternatives are examined equally using the same criteria and prioritization scale. AHP also allows for inconsistency in the judgments and provides a means to improve consistency (Saaty & Vargas, 2001).

3.3.1 SELECTION OF CRITERIA IN RELATION TO THE GOAL

The most challenging part of this process is structuring a decision problem and deciding what criteria to include in a hierarchical structure. A hierarchical structure consists of three levels: the top level representing the overall goal, the middle level consisting of the criteria and sub-criteria used to evaluate the alternatives, and the bottom level representing the actual alternatives for reaching the goal. This known as a top-down dominance relationship. Figure 19 shows the hierarchy structure of the decision problem being analyzed.

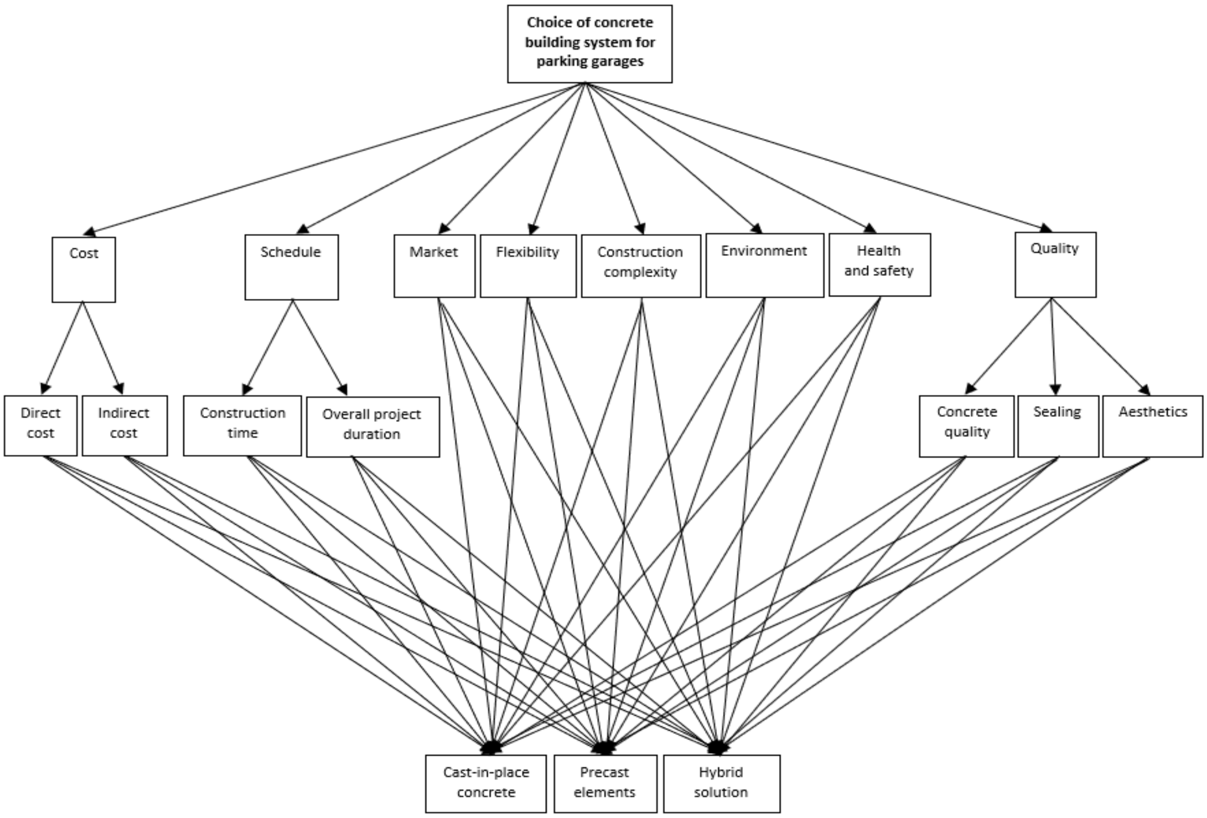


Figure 16: Hierarchy structure of the decision problem

The structure and selection of criteria for analysis are based on existing literature and expert knowledge gathered from field observations and interviews with key personnel involved in the reference projects. The selection of the criteria was based on a thorough analysis of the reference projects, Skadberg Alle and Mosvannet Park, as given in Table 10. These criteria will be further used for AHP analysis of the last reference project, Bykronen. The decision has already been made by the design team to build with cast-in-place concrete, but with AHP, we can conclude whether the decision was right or if it can be challenged.

Table 15: Selection of criteria and sub-criteria

Criterion	Sub-criterion	Description
Cost (C)	▪ Direct cost (C1) ▪ Indirect cost (C2)	Cost of materials, elements, labour, transportation, necessary equipment/machinery required for the construction process. Administration costs, establishment costs and other necessary infrastructure such as barracks and temporary storage facilities.
Schedule (S)	▪ Construction time (S1) ▪ Overall project duration (S2)	Time required to complete the construction of the parking garage. Cast-in-place can take longer time on-site, but prefabricated elements require more time in the design phase, hence overall project duration is considered (design, procurement, and construction).
Market (M)		Assessment of products in a price phase. How the demand for products in the market affect the choice of method. Capacity of logistics and supplier companies, and how it is related to enterprise risk of buying a service.
Flexibility (F)		Flexibility and adaptability to sudden changes and design requirements.
Construction complexity (CC)		Restriction of construction activities in relation to site conditions. Ease of access to the site for cranes, trucks, and elements arriving Just-in-Time. Weather patterns. Rig space and storage space for materials, elements, tools etc. Space for cranes. Flexible space conditions for multiple activities to occur simultaneously.
Environment (E)		Environmental impact of construction process and materials used. Best method for waste management.
Health and safety (HS)		Safety regarding risk of accidents during construction and operation. Health of the workers in the construction process (exhaust gases during asphalting for example). Connected to site- and space conditions.
Quality (Q)	▪ Concrete quality (Q1) ▪ Sealing (Q2) ▪ Aesthetics (Q3)	Necessary concrete quality required vs requirements in standards. Solutions for tightness of air and water, and corrosion. Appearance of the parking garage can be important for garages under apartment buildings. Connected to client acceptability and needs.

The nature of the AHP method is based on pairwise comparison of all the criteria. A questionnaire was distributed among experts involved with the last reference project, as the data gathering tool for the pairwise comparison. The questionnaire formed 73 pairwise questions totally, with five experts chosen specifically to answer. While making a pairwise comparison, a scale developed by Saaty is used to determine the relative importance of the compared criteria.

3.3.2 THE FUNDAMENTAL SCALE

Saaty developed a fundamental scale of values to represent the intensities of judgments as shown in Table 16. This scale has been validated for being the most effective in many applications by a group of people (Saaty & Vargas, 2001, p. 17).

Table 16: The fundamental scale for assessing the importance of activities (pairwise comparison)

Intensity of Importance	Definition	Explanation
1	Equal importance	Element ***a*** and ***b*** contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor element ***a*** over ***b***
5	Strong importance	Experience and judgment strongly favor element ***a*** over ***b***
7	Very strong importance	Element ***a*** is favored very strongly over ***b***; dominance demonstrated in practice
9	Extreme importance	The evidence favoring element ***a*** over ***b is*** of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed. For example, 6 can be used for the intermediate value between 5 and 7

The scale used in the questionnaire was slightly modified for some of the questions. The scale was applied as presented in Table 16 when comparing the main criteria against each other. However, when comparing sub-criteria against alternatives, the description of the numbers was adjusted while maintaining the 1-9 scale. For instance, in the case of direct costs, the number 9 represented "extremely higher costs" rather than "extreme importance". Despite these changes, the underlying meaning of the numbers remained consistent. The modifications were made to facilitate respondents' understanding of the questions and thereby enhance the validity of their responses.

3.3.3 ILLUSTRATIVE EXAMPLE FROM QUESTIONNAIRE

Total cost vs. Schedule																
Total cost																Schedule
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

This was the first question in the questionnaire where the main criterion "Total cost" was compared to the criterion "Schedule". If the respondent believes that total cost for the reference project has an extremely higher level of importance than Schedule, the respondent selects the number 9 under "Total cost". If the respondent believes they are equally important for the reference project, the respondent selects the number 1.

Cast-in-place vs. prefab elements																
Cast-in-place																Prefab elements
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

This is an example of when the scale was adjusted to make it easier for the respondents. “Total cost” was compared across the alternatives, and if the respondent perceives that cast-in-place has “extremely higher cost” than prefabricated elements, they will choose the number 9 under “cast-in-place”. This adjustment was made to ensure that the respondents can express their opinions accurately and consistently, and to avoid ambiguity or confusion in the interpretation of the scores.

3.3.4 EXPERT CHOICE

The weights assigned that represents the judgments of the comparisons are arranged in matrices for further calculations, using the numerical values from the fundamental scale. A sensitivity analysis is vital at the end of the analysis to study the influence of the criteria and to validate the solution. For an AHP task of this magnitude, it can be time-consuming to do the calculations manually. There are several AHP software that can perform the calculations, and Expert Choice has been the most widely used software while also being the most reliable. Expert Choice has a built-in tool that uses a mathematical algorithm called the Eigenvector method to derive the weights from the pairwise comparison data of the respondents (ExpertChoice, 2023).

Expert Choice provides the option to input respondent answers directly into the program. The number of respondents needs to be defined before performing pairwise comparisons for each of them.

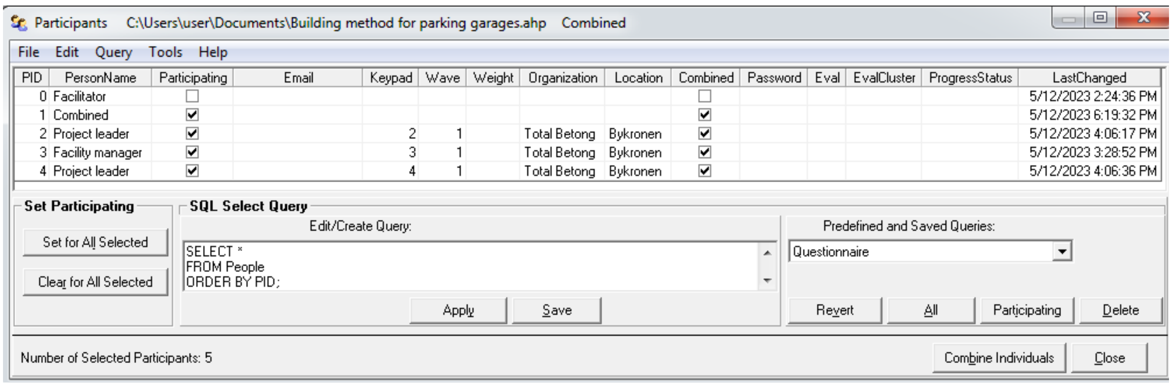


Figure 17: Participants of questionnaire

As mentioned earlier, the questionnaire was sent to five experts who are primarily involved in the design team and have sufficient knowledge regarding the reference project, Bykronen. Unfortunately, only three of them were able to answer. These respondents included a design manager, a construction manager, and a project leader. They were registered as respondents within Expert Choice, as shown in Figure 20.

3.3.5 EXPERT CHOICE CONSISTENCY RATIO VALIDATION TEST

After the comparative estimates from each relevant expert, a consistency check was conducted to assess the validity of the judgments The generally accepted range for consistency ratio (CR) should ideally be below 0.10 to ensure validity in the judgments (Saaty & Vargas, 2001). However, for this case, the CR for two respondents were slightly over this value, suggesting that judgements made during pairwise comparisons are slightly inconsistent. The CR should be as low as possible, but it is worth noting that the interpretation of the acceptable range may vary depending on specific discretion of the decision maker. Nevertheless, the consistency ratios given below are acceptable for this particular analysis, but continuing efforts to minimize inconsistency will enhance the credibility of the analysis. This was not possible, as the possibility of further adjustment were limited due to the availability of the experts.

Table 17: Consistency ratio (CR) results in Expert Choice

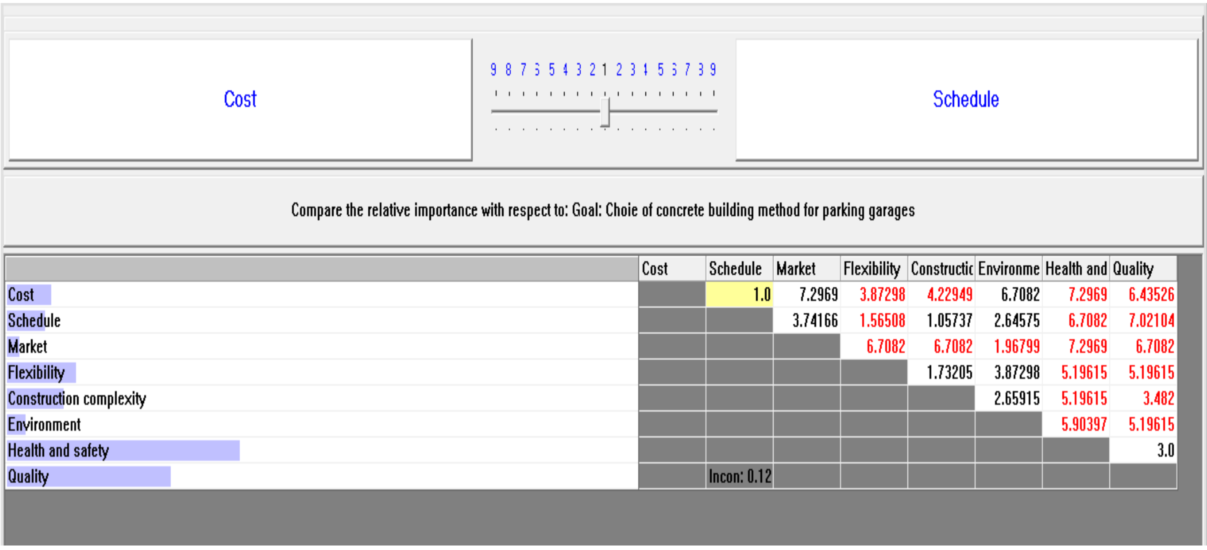
Respondent	Consistency Ratio (CR)
1. Design manager	0.16
2. Facility manager	0.11
3. Project leader	0.09

Chapter 4: Results and Discussion

This chapter consists of two subchapters. The first subchapter focuses on the outcomes of the AHP analysis conducted on the most recent reference project, Bykronen, which is currently under construction. Sensitivity analysis of the results are also performed. The second subchapter examines the necessary conditions for a meaningful choice between construction methods for parking garages. Factors that influence the choice of solution are analyzed and discussed with a Lean perspective. The findings are categorized according to the criteria established for the AHP analysis, as outlined in Table 7.

4.1 AHP RESULTS

As mentioned in Section 3.3, the Expert Choice software has been utilized for estimating priorities and carrying out sensitivity analysis of the results. Figure 21 illustrates the combined result of the pairwise comparisons of the three respondents. The overall consistency is given to be 0.12, which suggests a small degree of inconsistency.



	Cost	Schedule	Market	Flexibility	Constructic	Environme	Health and	Quality
Cost		1.0	7.2969	3.87298	4.22949	6.7082	7.2969	6.43526
Schedule			3.74166	1.56508	1.05737	2.64575	6.7082	7.02104
Market				6.7082	6.7082	1.96799	7.2969	6.7082
Flexibility					1.73205	3.87298	5.19615	5.19615
Construction complexity						2.65915	5.19615	3.482
Environment							5.90397	5.19615
Health and safety								3.0
Quality		Incon: 0.12						

Figure 18: Combined pairwise comparisons between criteria in Expert Choice

From all evaluations carried out on the selected 8 criteria and 7 sub-criteria, a table of relationships between criteria and alternatives was obtained seen in Figure 22 below.

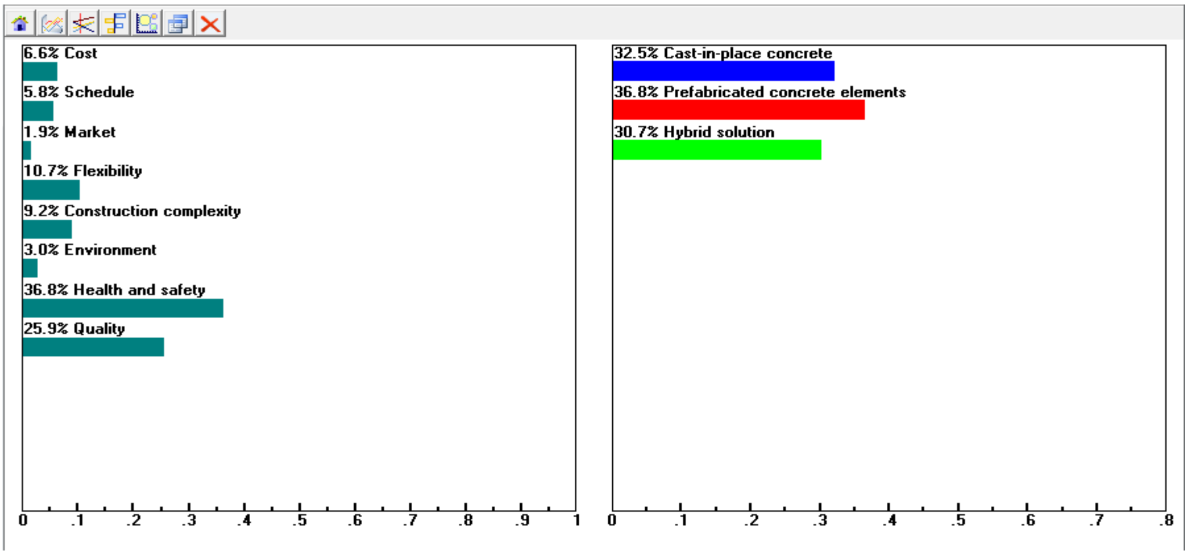


Figure 19: Dynamic performance of goal: choice of construction method for parking garage Bykronen

According to the analysis, building with prefabricated concrete elements constitute the optimal solution. The final solution is slightly inconsistent, as the overall inconsistency is given as 0.12. Although it exceeds the threshold of 0.1, given the complexity of the analysis and the number of elements involved, a ratio of 0.12 is considered acceptable. The best construction method for this particular project compared to the others have been illustrated to the right in Figure 22. “Cast-in-place concrete” is given an overall combined weight of 32.5%, “Prefabricated concrete elements” is given the highest weight of 36.8%, and a “Hybrid solution” is given the lowest weight of 30.7%.

Even though prefabricated elements have the highest priority, there is not much difference between the alternatives. Therefore, it is better to take a closer look at the sensitivity analysis of each respondent.

Figure 23 shows the performance sensitivity and dynamic performance of the design manager. It is evident that a solution with prefabricated elements is the most preferred by the design manager. On the right side of the figure, it can be observed that the factors “health and safety” and “quality” hold the greatest significance for the project compared to other factors, according to the design manager. “Schedule” also shows some importance in relation to the other factors. Consequently, the choice naturally falls on construction with elements as it is the method that ensures the health and safety of workers while maintaining the schedule and quality requirements. The design manager also has the highest inconsistency compared to the other respondents (see Table 17). This can also have a significant impact on the outcome.

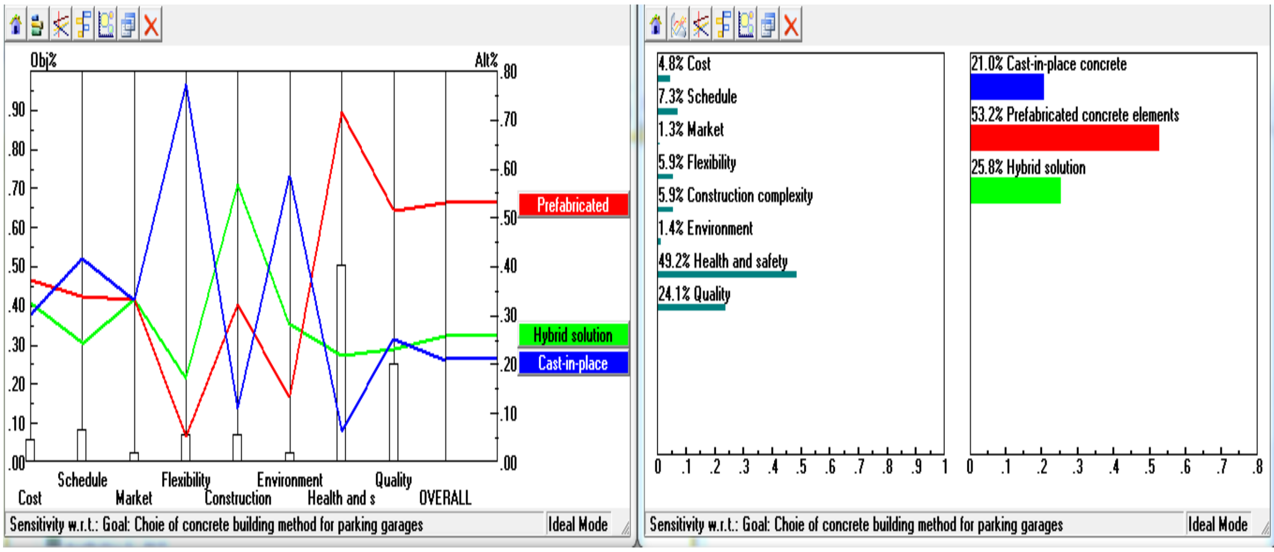


Figure 20: Performance sensitivity and dynamic performance of design manager

Performance sensitivity and dynamic performance of the construction manager and project leader are given below, respectively. For both, “Cast-in-place concrete” is preferred, although the differences between the alternatives are not significant. It is also evident that the factors have been given fairly similar importance. “Health and safety” and “Quality” are the most important factors here as well, but other criteria such as “Flexibility” and “Construction complexity” have received greater emphasis compared to the response from the design manager. This might be the reason why the choice of solution was made in favor of cast-in-place concrete, as it offers greater flexibility in design and change requirements.

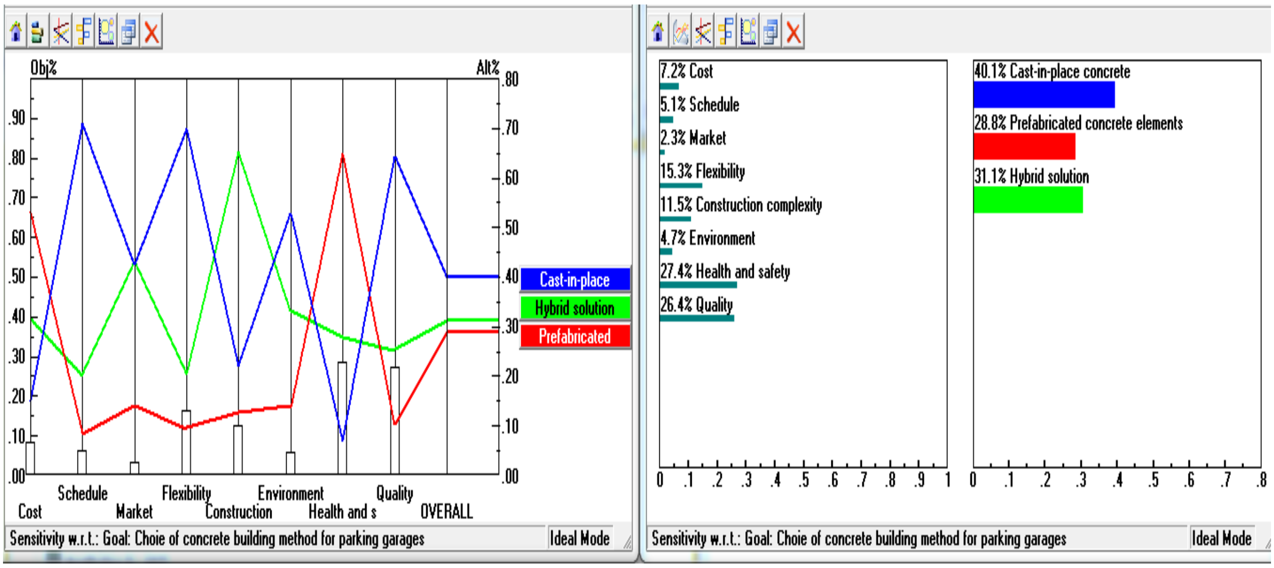


Figure 21: Performance sensitivity and dynamic performance of construction manager

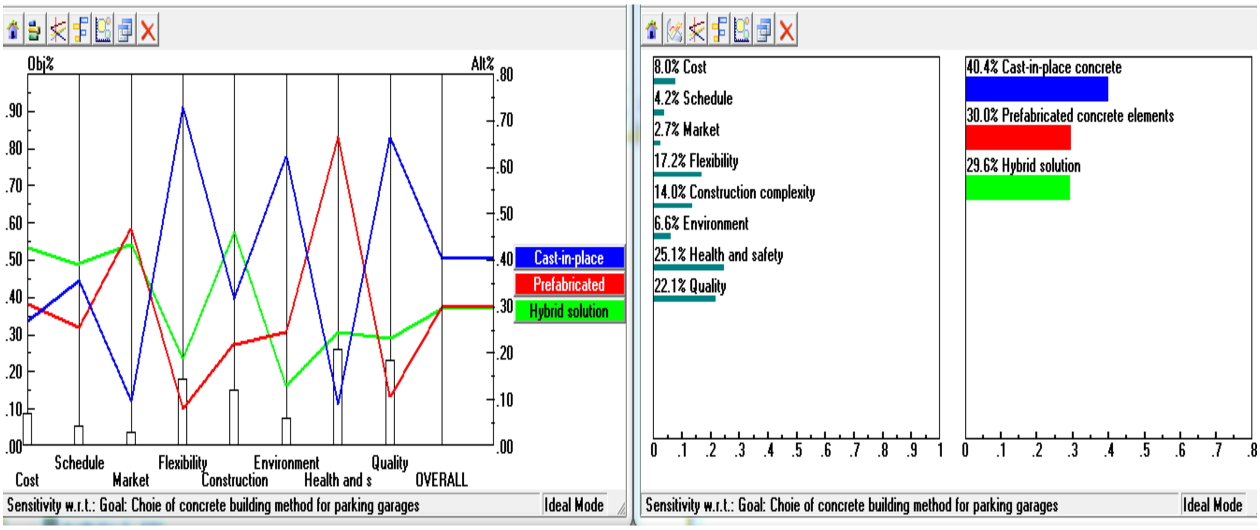


Figure 22: Performance sensitivity and dynamic performance of project leader

4.2. DISCUSSING PREREQUISITES FOR CHOICE OF SOLUTION

Cast-in-place concrete and prefabricated concrete offer different possibilities and limitations. The construction methods were presented objectively in the theory chapter. This chapter delves into the prerequisites necessary for employing these construction methods and examines the resource utilization associated with each alternative from a Lean perspective. The data obtained from the AHP analysis and the reference projects, along with insights from interviews, serve as the basis for this analysis.

Several influencing factors affect the selection between construction methods for parking garages. Some factors may entirely rule out certain alternatives or complicate the decision-making process. The following section will shed light on the factors outlined in Table 15, along with various aspects that should be considered.

4.2.1 OWNER IMPACT IN PROJECT DELIVERY

The influence of the owner has a significant impact on the choice of solution for specific projects. The contractor may be restricted by the owner in selecting a solution, depending on the owner’s tolerance and budget for maintenance. The level of freedom in choice depends on the form of contract and the collaboration between the contractor and the owner. Project Delivery (IPD) is a Lean Construction practice which align the owner, design team, construction team as well as other subcontractors onto a single contract (Kuchera, 2015). Although IPD is not a direct Lean tool, several Lean strategies and tools can be implemented within such collaboration, such as the Last Planner System, Value Stream Mapping, and Pull-

Planning. The traditional way of managing risk is to add buffers for time, materials and costs (Pasquire, 2002). By utilizing integration, the risks and financial benefits is shared with a single contract. IPD lays the foundation for collaboration between stakeholders and suppliers regardless of the relationships they have, with the aim of optimizing the results, reduce waste, increase value, and maximize efficiency through every phases of a project (AIA, 2014).

IPD challenges traditional forms of contracts like main contracts, general contracts, and even turnkey contracts. The traditional contract forms either assign the design responsibility to the owner or to the contractors. This can lead to disagreements and make it difficult for the contractors to choose the construction method for a project. Currently, companies specializing in prefabricated elements have more expertise in the design of such constructions. Therefore, early involvement of these suppliers is desirable, as it saves costs and time for the owner.

On the other hand, for separate contracts, the quality may be better because the contractors are solely focused on their specific tasks. However, the downside of this approach is that the owner's opportunities for cost savings and waste reduction are limited. A flexible owner often has time for a collaborative phase, where proposed changes are discussed with all stakeholders. An early decision must be made because prefabricated elements have longer delivery and design lead times compared to fresh concrete.

4.2.2 COST

During the interviews, it was revealed that to remain competitive, other factors need to be considered, particularly operational cost. Therefore, the costs for this study are divided into direct cost and indirect costs. Another aspect that will be discussed in this chapter is the cost per parking space. The more parking spaces that can be obtained from a proposed solution, the more the cost can be divided among the units. Therefore, the number of parking spaces is a factor to consider when discussing costs.

When it comes to the choice of construction method, the immediate attention is often given to the direct costs associated with the processes. From the interviews and previous studies, it has been found that the difference in direct costs (design, production, and assembly) between cast-in-place concrete and prefabricated elements is not significant (see Table 8). Hence, the cost is not given as much emphasis as the other qualitative factors, as demonstrated by the combined importance degree of 6.8% assigned by the respondents for the AHP analysis. However, for smaller projects, direct cost can have a bigger say in choosing construction method. For both construction methods, a tender price is calculated. Calculation of cast-in-place constructions includes the square meter price for formwork, reinforcement, and fresh concrete. On the other hand, prefabricated elements have a slightly variable square meter price depending on project specifications. The square meter price decreases as the size of the elements increases. However, the greatest variable for direct costs is the transportation costs. Margins become smaller, and project profitability is reduced with greater distances.

Nevertheless, it is the indirect costs where there is a significant potential for improvements. Rig and operational costs incur significant expenses on a daily basis for every part involved. This is related to the increased need for staffing. For cast-in-place buildings, there are several additional costs that estimators must consider when providing a project bid compared to building with prefabricated elements. For prefabricated projects, precast suppliers provide a complete offer with the inclusion of installers, project managers, and cranes in addition to the elements, transportation within a certain radius, and design. The cost of project design depends largely on the contract form and is therefore calculated separately by the contractor.

Crane costs also need to be considered separately, and they can be as market dependent as the elements. Table 18 shows the estimated prices for crane rentals, with variations depending on crane sizes. As mentioned, suppliers often provide mobile cranes for prefabricated solutions, but when working with cast-in-place concrete, there is often a need for a tower crane used for lifting reinforcement, concrete, and formwork elements.

Table 18: Crane usage cost

Crane utilization	Cost
Monthly rent	NOK 35 000
Setup cost	NOK 40 000 – 60 000
Rent of crane operator	NOK 490 per hour

Although cost estimates are provided for various expenses, costs are generally highly specific to each project. Nonetheless, it is reasonable to use estimates and average prices during the planning phases to weigh the advantages and disadvantages of the construction methods. Market conditions influence costs, especially with high demand and long distances. Cast-in-place constructions are less influenced by the market than prefabricated constructions.

The reason why costs have been given less weight by the respondents in the AHP questionnaires is primarily because there are not significant differences in direct costs for large projects. Secondly, the actual costs often differ greatly from what was anticipated in the initial bids. For example, an element building is designed and produced before the actual assembly takes place. However, problems can arise that lead to delays and changes in plans, resulting in higher costs. Cast-in-place buildings are therefore less predictable than element buildings, as progress and costs associated with progress depend heavily on production operations and workers.

Lean improvements for cast-in-place buildings have greater potential for cost reduction during the production phase, while element buildings have greater potential for improvements related to Lean in the planning phase. The Last Planner System and the concept of identifying waste in activities and processes can lead to substantial cost reduction, especially in indirect costs.

According to the CEO, another aspect of cost reduction is to identify the value of adding an extra parking space to the solution. In line with an ever-evolving housing market, the shortage of parking spaces is becoming apparent. According to an article written by Marschhäuser (2020), the value of a parking space in Stavanger and Oslo is around NOK 250 000, but can vary up to NOK 700 000, depending on the project. Hence, seeing the value of bringing in an extra parking space is valuable for the builders and owners. Some strategies for this include optimizing space utilization by using efficient parking layouts, such as multi-level parking or compact parking. This allows for more cars to be accommodated. The concrete manager highlights the ability of prestressed hollow core slabs to bear loads over longer spans, which can reduce the need for columns. A better parking layout can be achieved by this. Figure 26 shows parking garage for project Mosvannet Park where 15-meter-long prestressed hollow-core slabs are used to create more space.

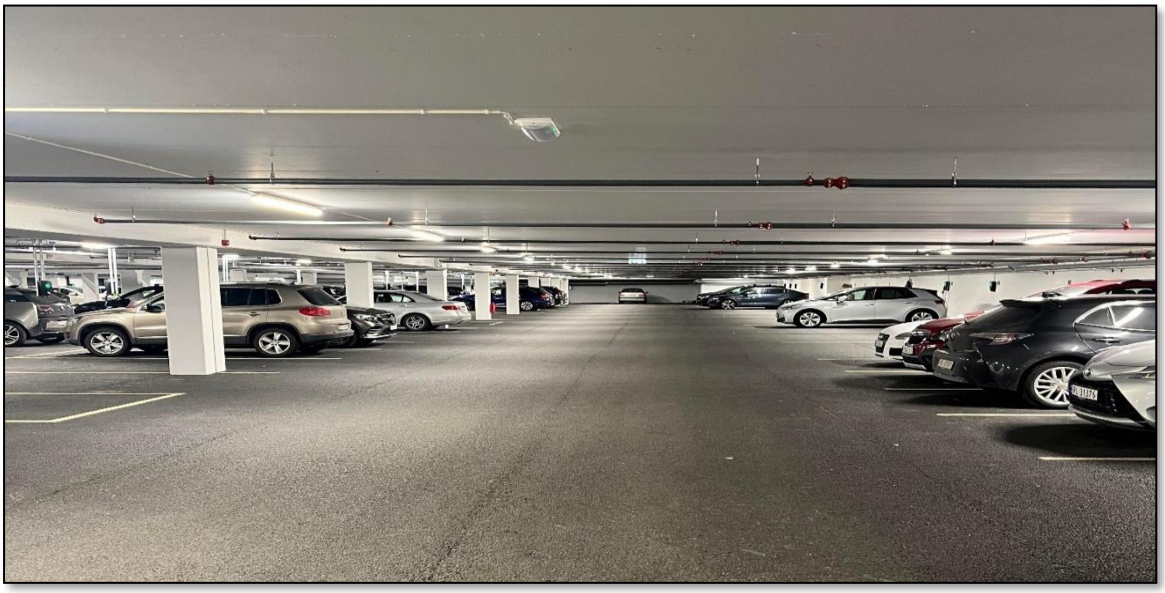


Figure 23: Parking garage Mosvannet Park

4.2.3 MARKET

The sales manager at Block Berge Bygg AS believes that value creation in each element is necessary to stay competitive in the market. Prices for hollow-core slabs, for example, are under pressure and have a low value due to the high demand. Therefore, the focus is on adding higher value to the elements in the factory, reducing the proportion of transportation costs as a major concern. The sales manager emphasizes Lean production and innovative solutions as important aspects of value creation. Being an early adopter of innovative solutions and methods is crucial to gain a competitive advantage and it highly depends on the corporate culture. Examples include product standardization and delivering pre-insulated and covered elements. He further explains that the cost associated with transportation will not change since the total weight of the elements remains the same.

The CEO of Total Betong highlights the importance of market demand for products in a pricing phase. It is a critical factor in choosing the construction method for parking garages. Fortunately, the reference projects have a short distance from the prefab supplier, Block Berge Bygg AS. For example, the distance from the supplier to Mosvannet Park is only 9.2 km. This provides the designers with the flexibility to consider several construction methods, but it also depends on the capacity of suppliers and the freedom to choose in relation to enterprise. A solution with prefabricated elements is immediately ruled out if the distance is too far from a supplier due to the high transportation costs.

4.2.4 SCHEDULE

Time available for the overall project duration is crucial, as it affects the cost to the customer with financing and rig costs, salary administration, barracks, operations, etc. Several interviewees highlight shorter construction time as an important advantage, and that it reflects the finances of the project. A suitable project timeframe allows for flexibility in choosing the construction method, while a shorter construction duration can be a decisive factor in favor of switching from cast-in-place to prefabricated elements.

Building with prefabricated elements generally leads to quicker implementation, but the total project duration may be longer. The schedule is therefore divided into construction time and total project duration for the AHP analysis. Tendering, engineering/design, production, assembly, and installations are included in the total project duration. The questionnaires indicated that the total project duration is only slightly longer for building with elements compared to casting. The reason being is that with casting a lot of time is spent on site even though the planning/design phase is shorter.

As mentioned in the theory chapter, the cast-in-place concrete process involves several stages. Production of precast concrete doesn't require any waiting time on the construction site, as the elements that are delivered are already cured and constructed, requiring only assembling. Due to the 28-day curing period and the waiting period for each component, cast-in-place concrete is time-consuming. The precast procedure conserves this time. Thus, the company can save time and money on waiting time and labour costs. To produce concrete elements using the precast method, a contractor must be skilled with technology and have extensive knowledge and experience. In cast-in-place, the demands on the contractor are not as high.

4.2.5 CONSTRUCTION COMPLEXITY

Construction complexity is included as a factor for the AHP analysis to indicate the importance of good space conditions, good logistics and transportation channels to and from the construction site. The combined result of the respondents shows that main criterion, “Construction Complexity”, has been given more importance than “Cost”, “Schedule”, and “Market”. This shows the importance of considering qualitative factors rather than only the quantitative ones.

The concrete manager points out that space is one of the biggest reasons for not choosing cast-in-place construction for a project. Prefabricated elements arrive at the construction site according to the Just-in-Time principle, and it is most optimal to hoist the elements straight from the trucks. But it can also be problematic if the elements do not fit or need to be modified. Then large storage space is needed since elements have to be stored carefully to prevent them from damages. If there are poor conditions for the storage of products and other equipment, an intermediate storage space must be considered. As mentioned earlier in the paper, the least possible storage of products and equipment is desirable, as a lot of storage leads to additional indirect costs.

Consideration of space to set up a tower crane or use of a mobile crane is also an important input in the choice of construction method. As mentioned earlier, a permanent crane in the form of a tower crane is required when casting. For prefabricated structures, a mobile crane can be used. Whether there is space to set up a tower crane or whether there is space to drive around a mobile crane must therefore be assessed according to the site conditions and available space.

Currently, for larger projects, system formwork and permanent formwork such as filigree slabs are used. Although the AHP results suggest construction with elements as the best solution, it was already decided for the Bykronen project that everything should be cast-in-place. According to the concrete manager for this project, filigree slab is used as floor separators to reduce construction time and space requirements for reinforcement and formwork. Filigree slab combines the advantages of both prefabricated and cast-in-place construction. It can be hoisted straight on, where any technical equipment such as electrical and ventilation can be laid down before casting the top deck (FABEKO, 2023).

Figure 24: Filigree slab (FABEKO, 2023) **Figure 25:** Bubble Deck (Constructor, 2023)

During our field observations, one of the project leaders discussed this idea of using bubble deck slabs, which is almost the same as filigree slab, where hollow plastic spheres (plastic bubbles) are incorporated in the floor, to virtually eliminate all concrete from the middle of a floor slab not performing any structural function. In that way, the structural dead weight can dramatically be reduced (Constructor, 2023). However, this idea was not implemented due to uncertainties expressed by the design team and suppliers. Encouraging such innovations and fostering open discussions during pull-planning meetings involving all stakeholders can help address these uncertainties. This is linked to the corporate culture of continuous improvement to reduce waste and increase in efficiency.

Other site constraints such as topographic information, soil reports, and codes and ordinances are important to consider when evaluating a potential site for constructing a parking garage. A topographic survey will define the slop of the site, and it can be utilized to reduce internal ramping in a parking structure according to the concrete manager. This will eventually lead to lower costs and also gives the opportunity to fit in additional parking spaces. He also points out that the added cost for extra foundation can be significant if there are soils with poor bearing capacity on the site. Building codes and regulations should also be considered for height limitations and other measurements that can affect the allowable area on a parking structure.

4.2.6 OPERATIONAL FLEXIBILITY

One of the biggest reasons for choosing cast-in-place structures is projects that have high requirements for adaptability. This can quickly rule out prefabricated elements as the elements act as LEGO pieces: once designed and manufactured, they are largely dependent on remaining as manufactured. There is also a risk of cutting the reinforcement when cutting holes in the elements. Therefore, it makes sense to build with cast-in-place structures as they are adaptable and flexible to changes in design and alterations, not to mention shaping. Structures with special design are best suited to cast-in-place since the formwork determines the shape of the structure.

In contrast, prefabricated solutions are flexible in terms of the general internal areas that can be achieved with long spans. For underground parking garages, large openings with minimal bearing in the middle are desirable to achieve better parking utilization. Prefabricated solutions provide flexibility in this way, but their adaptability is very low compared to cast-in-place structures. With effective planning with suppliers and the design team, the need for adaptability can be reduced. Thus, prefabricated solution can be the most flexible in terms of time, cost, and quality.

4.2.7 QUALITY

When it comes to building a watertight structure with fewer joints, cast-in-place construction is the best option. When utilizing prefabricated elements, it is typical to incorporate additional topping and grout joints. However, it is important to acknowledge that each joint presents a potential risk and may contribute to the likelihood of leaks or water infiltration. Parking lots under new apartment buildings usually have high aesthetic and design requirements, which is meant to reflect the appearance of the entire block. Developers require good concrete quality, good sealant of joints, focus on aesthetics, and overall good appearance to be attractive in the market for potential customers. This is reflected by the responses from survey respondents where the combined importance rating for “Quality” is second only to “Health and Safety” with 25.9%.

According to the sales manager of Block Berge Bygg AS, the implementation of Lean principles resulted in an enhanced quality of the elements. This can be attributed to the team’s collective readiness to identify and address any errors at the earliest stages of the process. Furthermore, he points out that any errors that are discovered afterwards impose 3 times the original cost of the elements, and this is doubled if the elements have already been delivered to the customer. The main cause is usually poor communication, and since the introduction of Lean and the use of Lean techniques, this has improved massively.

Concrete quality

Achieving the necessary concrete quality is essential for both building methods to meet the high standards required for parking garages under new apartment blocks. Strength and durability of the concrete is important to ensure long term integrity of the structure. The concrete mix should be carefully measured according to standards to achieve desired concrete quality. Given that it is produced in a factory before being transported to the construction site, precast concrete is simple to manage and maintain. Therefore, it is simpler to maintain the quality of the concrete components throughout the procedure. Simultaneously, it is simpler to regulate the water-to-cement ratio, resulting in improved quality. On-site concrete casting is performed by workers. Thus, the quality can differ considerably from mix to mix, and bad weather can delay the construction process. The method of prefabrication is unaffected by weather conditions. The elements being made are prefabricated and therefore will not shrink, distort, or move regardless of the weather.

During our field observations in February 2023, we noticed instances of poor concrete quality in some of the casted walls for Mosvannet Park project. The concrete manager indicated that these issues were caused by either bad cement-to-water ratio or inadequate vibration during the concrete pouring process. Furthermore, there were instances of water leakages, caused by multiple repetitions of the concrete topping on decks. As mentioned earlier, the parking garage for this project was constructed with a hybrid solution of cast-in-place concrete and prefabricated elements. There is therefore no method that ensures good quality completely, but it can be achieved by effective communication and cooperation. These quality issues not only impact the durability of the walls but also have implications for the overall appearance of the parking garage's final scheme.

Sealing

Construction joints in precast consist of many critical elements that need to be taken care of. In cast-in-place concrete, there are not many construction joints which means that it does not require as much attention in the construction process. Prefabricated elements come with several joints which can lead to water leakages, and thus have higher maintenance needs. Lean Construction techniques such as rigorous quality control inspections can be employed to detect potential weaknesses that could damage the concrete strength and durability which can lead to leakages. Standardization of elements can help ensure proper quality and reduce risk of leaks. From the questionnaires, cast-in-place concrete is clearly preferred in terms of concrete quality and sealing of structures.

Aesthetics:

Aesthetics plays a significant role in creating a visually pleasing environment to attract potential customers. Developers and owners prioritize factors such as surface finishes, architectural details, and colour matching in the overall structure. The aesthetics requirements can be achieved with both building methods, but cast-in-place concrete is best for joint treatments and finishes. Collaboration and early involvement of architects and designers is crucial to address concerns regarding aesthetics during the initial planning stages.

4.2.8 ENVIRONMENT

In this task, environmental impact and resource use are linked. Berg (2008) argues that better conditions for reducing environmental impacts are achieved by facilitating a more industrialized production, in this case, facilitating more standardization and prefabrication. Prefabrication generally generates little waste compared to the casting process. The sales manager states that the residues generated can be reused for other elements, which are mostly part of the waste in a casting process.

As mentioned earlier, there is a smaller amount of waste in prefabricated construction, as compared to cast-in-place. Since it is manufactured in a factory, less water, cement, and steel are used, reducing the amount of material required and is overall better to control waste compared to cast-in-place construction. Another advantage of the precast method is the reusability, expansion, and reassembly of the materials, which is challenging with the alternative method. With increased standardization of products and adopting a circular approach to managing the process, waste and pollution can be minimized.

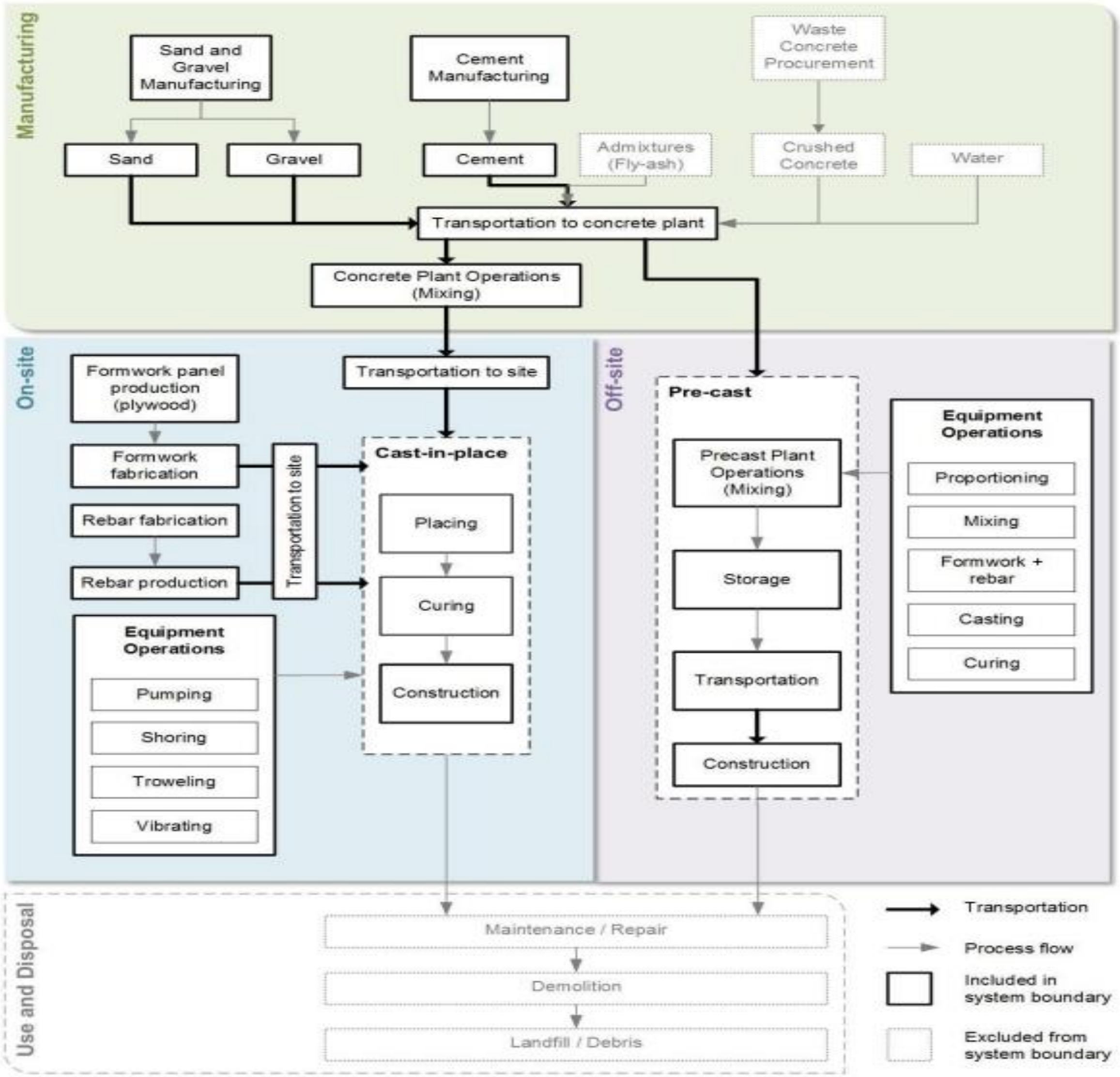


Figure 26: Value Stream of Cast-in-place concrete and precast elements (Ramsey et al., 2014)

Much of the theory chapter was about Lean in terms of the value of identifying waste and strategies to remove it immediately. This involves following the value stream and performing inspections in “Gemba” – where everything happens. Figure 29 shows the value stream for both construction methods from the production process to disposal. By going through the value streams with the project team in Total Betong AS, we can conclude that a cast-in-place construction process involves more activities and processes that are non-value adding compared to a prefabricated solution. As shown in Figure 29, certain activities related to formwork can be considered non-value in a cast-in-place process, and not least reshoring after formwork removal. In a prefabrication process the need for extensive formwork fabrication is minimal since the formwork can be adjusted and fixed for efficient element production. Another important aspect is the need for tenting in bad weather conditions when casting. In prefabrication, the production and curing process is done under controlled environment and conditions. In this way, the use of resources is significantly less for prefabrication which can lead to a reduction in costs related to manpower, resources, and use of other equipment.

As mentioned in section 2.5, it is the production of cement that accounts for most of the CO2 emissions related to concrete construction. Therefore, it is important to focus on innovative solutions to reduce the impact on that front. Solutions mentioned to improve this aspect are the use of environmentally friendly solutions in the production of cement, such as replacing fossil fuels with waste materials and biomass. Through the interviews, it appears that recycling of waste materials is key, and prefabrication has the best conditions for recycling and reuse. Materials such as silica fume and fly ash contribute to large amounts of emissions in the production of cement, and in prefabrication it is possible to recycle these for reuse, compared to the casting process where they can quickly become waste. The more you prefabricate the less the environmental impact. The main weakness of it is that everything has to be done right, but it can also be a strength to improve the culture within the company.

During the interviews conducted for the Skadberg Alle and Mosvannet Park projects, it was evident that waste management was generally well-controlled. It was measured in tons, and divided into several categories such as wood, concrete and other heavy building materials, contaminated concrete, paper, cardboard, gypsum-based materials, among others. When constructing with prefabricated elements, there is less waste which leads to less costs related to waste management, not to mention time and manpower that can be used for other activities. By knowing the 8 wastes in Lean (Table 2), one can identify earlier what is value adding and non-value adding.

4.2.9 HEALTH AND SAFETY

From the combined and individual summaries of the AHP analysis, “Health and safety” has been given highest importance when choosing a construction method. The criterion has received an importance degree of 36.8% compared to the other 7 criteria. This is no shock as the construction industry is one of the largest industries in the world with many people involved daily on the construction site. Health, safety and environment (HSE) is an increasingly important factor in the industry and there are regulations such as the “Arbeidsmiljøloven” in Norway that help to ensure workers' rights and obligations

(Arbeidstilsynet, 2023). Often each company has its own HSE regulations and procedures. There are regulations that require work to be documented by means of an HSE plan.

The greatest danger comes from crushing injuries when large elements have to be handled and moved a number of times before assembly. It is therefore important not to carry out other activities in parallel in such cases. For that reason, a hybrid solution of both construction methods can be risky although it can also be profitable.

The CEO highlights another health issue that is important to consider. Cast-in-place columns make it easier to asphalt under open ceilings which reduce the risk of ingesting dangerous gases. When building with elements, additional steps are required, such as laying a cover or setting up temporary struts as temporary support before paving can take place (see Figure 30 and 31). This is a challenge with the use of elements that affects the operation of the site as it can be seen as non-value adding steps, but most importantly, the health of employees is at risk.

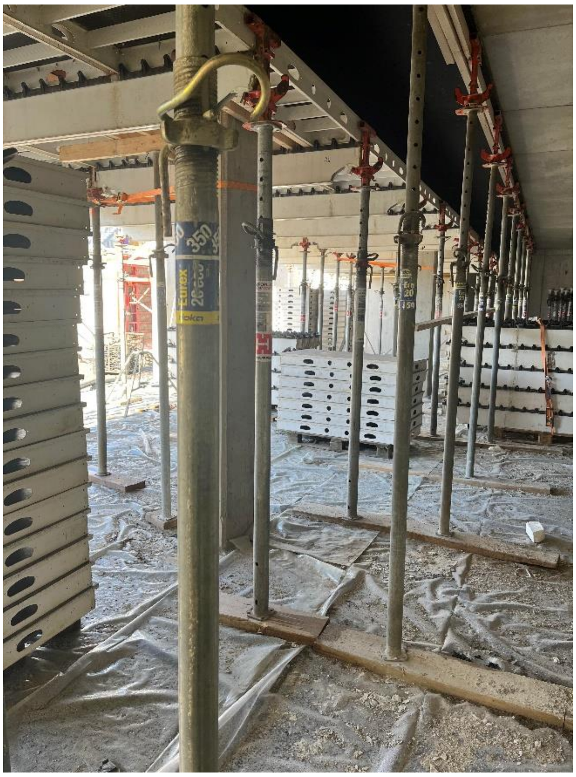


Figure 27: Temporary struts


Figure 28: Pavement issues

Chapter 5: Conclusions and Recommendations

The purpose of this task is to raise the competence in all phases of a construction project when determining the appropriate concrete building method for parking garages. This chapter is structured into sub-chapters to address the research questions, which, in turn, provide insights into the overall research objective. Finally, recommendations for further research will be presented.

5.1 RESEARCH QUESTIONS

How can Lean Construction principles and tools be applied to optimize the decision-making process for choosing the right building method for parking garages?

First and foremost, it is important to implement the principle of continuous improvement within a company culture. Lean Construction encourages a mindset of constantly seeking better ways to optimize outcomes. This has similarities with the choice of construction solution for underground parking garages, as the solution is project specific and influenced by several qualitative factors in addition to the usual quantitative factors: cost and time. It is essential to have commitment and understanding between the different actors involved in the project in order to make a choice that is profitable for all parties. Even though AHP is not a Lean tool in its traditional sense, it can be used as part of a broader Lean initiative to optimize decision-making processes, especially when evaluating multiple criteria and complex alternatives.

Secondly, Lean Construction focuses on minimizing waste while maximizing value creation. This involves the ability to identify all forms of waste, which comes in various tangible and intangible ways. Non-value adding activities and processes are considered the nontangible kinds, and need to be identified so that resources can be used more efficiently. This requires a shared view of the bigger picture in the value chain and a sense of ownership in what you do. Implementing pull planning techniques such as the Last Planner System allows for collaboration among all stakeholders involved in a process of decision making.

What are the key factors when choosing building method for parking garages?

Based on the responses to the questionnaires from the three respondents and interviewees, “Health and safety” is by far the most crucial factor when choosing the construction method for underground parking garages. The degree of importance is demonstrated by 36.8% in relation to the other criteria and is significantly higher than the most common quantitative factors: time and cost. One of the main focuses in today's construction industry is precisely health and safety. It is worth noting that building with prefabricated elements carries a lower risk in this regard. However, in the event of unforeseen circumstances, the consequences can be more severe compared to incidents in a casting process. Thus, challenges exist for both construction methods in relation to this aspect.

"Quality" and "Flexibility" rank as the next two most important factors, with cast-in-place construction performing better in these areas. However, personal preference plays a significant role. From an objective perspective, both methods can largely meet the requirements for quality and flexibility. Regardless of the chosen solution, cast-in-place concrete is used for foundations. In terms of appearance, both methods have their advantages and disadvantages. Cast-in-place concrete provides neat surfaces when accurately executed, but it requires favourable circumstances and conditions. Concrete elements, on the other hand, are manufactured indoors under controlled conditions, which ensures better concrete quality. However, multiple joints can be a disadvantage in terms of appearance and pose a potential risk of leaks.

The expression “Time is money” is widely used in the construction industry by the professionals. The data collection through this study suggests that direct costs does not significantly differ for large projects. Furthermore, it may seem that cast-in-place construction is cheaper, but then all conditions must be present if it is to be the best option. The method requires a substantial amount of on-site time that you can't afford, as it imposes additional indirect costs. It also demands a significant amount of space, and the expenses associated with temporary storage and construction loans can be costly, prompting clients to expedite the project schedule to minimize these costs.

To what extent are parking garages under apartment blocks suitable for construction with prefabricated elements?

A prefabricated building seems like a big jigsaw puzzle. If several wrong pieces are made, it is impossible to put it all together. Larger parking garages with intricate designs may require more customization, which could make prefabrication more challenging as it depends on the knowledge and skills of the project team. For simpler and standardized layouts, prefabricated elements can be highly efficient. In underground parking garages, column-free spans with expansive wall and roof areas are preferred to optimize parking utilization and accommodate additional parking spaces.

Most interviewees highlight that underground parking garages are suitable for prefabricated buildings as they can be built with many similar elements. If done correctly, this can save time in design, production, and installation. The stigma created of prefabrication of compromising quality compared with cast-in-place concrete has to be turned. Another aspect that makes prefabrication suitable as a construction method is because of the advantage of short construction time when early handover is needed. Parallel construction and a hybrid solution of both methods was highlighted during the interviews as a major advantage to shorten construction time. Furthermore, when dealing with tight spaces where rigging becomes problematic, prefabrication becomes a suitable construction method.

5.2 RECOMMENDATIONS

Based on the AHP results, prefabrication is the most preferable solution amongst the selected respondents. However, it is difficult to conclude this master's thesis as there are many aspects that could be further explored. According to the interviewees, availability of time is decisive for the choice of solution, but from the AHP results it can be seen that "Health and safety" dominates the other criteria. Another aspect emphasized in the interviews is the potential loss of the concrete profession when using prefabricated elements. This observation aligns, such as the findings by Alhady (2020), where it is evident that many professionals tend to avoid prefabrication as it may undervalue their work. This relates to traditional construction and planning methods, where individuals may not feel a sense of ownership in their work (see Table 1). As discussed earlier, Lean principles and Integrated Project Delivery (IPD) challenge the traditional methods of collaboration and execution.

It is important to make sure that the design team focuses on the collective benefit to both the company and society, rather than individual concerns. Prefabrication seems like the best option as it aligns well with Lean Construction principles, promoting standardization and the reuse of waste materials. Both construction methods are well suited as execution methods, but ultimately one has to study the project-specific details of each project. By identifying and discussing critical factors with the building owner and project stakeholders, one of the options can maybe be ruled out immediately.

5.3 FUTURE RESEARCH IMPLICATIONS

This issue remains open, with several aspects that can be further studied. The paper has addressed relevant perspectives within the context of the reference projects and the views of the interviewees. The emphasis has been on developing a comprehensive understanding of the topic, leading to the utilization of primarily qualitative research methods. Due to challenges in obtaining highly reliable and valid data, there was less emphasis on quantitative research methods and numerical analysis. In order to document the findings with greater certainty, future studies could incorporate more quantitative analysis of building physics calculations, as well as costs. One suggestion is to develop a measurement tool that collects different key performance indicators (KPI) to identify key figures for time, cost, environment, and other relevant factors.

The AHP method was utilized to analyse quantitative factors, but it can be further improved in future studies. The obtained result had an overall inconsistency of 0.12, indicating that the responses given by the respondents were not consistently aligned. It was problematic to get the respondents to give revised answers as time was limited. This aspect could be improved by allowing more time for data collection and analysis. Additionally, future studies could consider expanding the analysis by incorporating additional main and sub-criteria, as well as including a broader range of experts in the field to enhance the reliability of the results. A long-term objective of this thesis is to establish a foundation for analysing construction method choices across various project types by developing a program that challenges Expert Choice. This program would enable experts to provide simultaneous responses through a cloud-based platform, thereby saving time in survey preparation and data collection.

Furthermore, a thorough analysis of key environmental impact indicators associated with both construction methods could be undertaken, considering its significant long-term implications.

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APPENDIX

Intervjuguide

Bakgrunn og formål

Masteroppgaven går ut på valget mellom prefabrikkerte betongelementer kontra stedstøpt betong i parkeringskjellere, med Lean tenking. Elementløsninger er en Lean-løsning og oppgaven er naturligvis vinklet mot denne metoden. Det er derfor interessant og relevant for oppgaven å innhente informasjon ved intervjuer med aktører i bransjen for å høre om deres erfaringer og tanker rundt problemstillingen.

Intervjuguidens inndeling

Intervjuguiden er delt opp i 3 deler:

1. Informasjon om intervjuet og gjennomføring av det.
2. Generelle spørsmål om intervjuobjektet og ditt personlige forhold de to byggemetodene.
3. Utdypende spørsmål som baserer seg på Lean og fremdriftsstyring.

Gjennomføring av intervjuet

Intervjuguiden, med tilhørende spørsmål blir sendt ut til intervjuobjektene på forhånd slik at det er mulig å se gjennom spørsmålene og forberede seg før intervjuet.

Intervjuene er ønskelig å gjennomføre via Microsoft Teams, men det er også åpent for andre forslag. *Det er tiltenkt å ta lydopptak av intervjuene. Hvis noen ved formodning ikke ønsker dette, bes det om å si fra om dette.*

Svarene gitt under intervjuene vil bli brukt sammen med tilegnede dokumenter og litteratur for å kunne svare på problemstillingen. Intervjuobjektenes reaksjoner, ytringer og utsagn vil bli holdt anonyme med mindre annet blir avtalt.

Dersom noe er uklart under intervjuene, oppfordrer jeg dere til å spørre for å avklare ting.

Spørsmål

Bakgrunn

1. Kan du fortelle litt om deg selv og din rolle?
2. Kan du fortelle litt om hvordan produksjon skjer hos en prefableverandør når de først får inn en bestilling? Hvordan er markedet når det er høy ettersøprsel, hva gjør dere da?
3. Har dere vært med i en prosjekteringsfase for å f.eks bestemme løsninger for elementer? Hvilke elementer som er fordelaktig å bruke for et prosjekt? Er det et godt samarbeid med prosjekteringsgruppen da?
4. Kan du fortelle litt om fordeler og ulemper ved stedstøpt betong og prefab elementer, spesielt for parkeringskjellere?
5. Hvilken metode er fordelaktig ved utforming av en parkeringskjeller, og generell brukbarhet av anlegget?
6. Hva er løsninger for tetthet/hvordan redusere risiko for lekkasjer? Tekking osv av hulldekke, hvordan er kvaliteten sammenlignet med stedstøpt i slike tilfeller.
7. Tid er et viktig aspekt, hvilken metode optimaliserer ventetid og produksjon best samtidig som kvaliteten er bra? For eksempel plattendekke sparer mer tid, kan du fortelle litt om det?
8. Hvilken metode anbefaler du? F.eks.:
   metode 1: alt stedstøpt - stedstøpte fundamenter, yttervegger, innervegger, sjakt, søyler, bjelker og dekke).
   Metode 2: Kombinasjon. Stedstøpte fundamenter, yttervegger, sjakt. Betong element i innervegger, søyler, bjelker og hulldekke (kanskje plattendekke med klosser?).
   Metode 3: alt i elementer.
9. Hva vet du om Plattendekke og Bubbledekke? Tror du det kan være en mulighet for parkeringskjellere?
10. Hva er dine råd om valg av løsning, hva tror du er den beste løsningen for parkeringskjellere under boligblokk med tanke på tid, kvalitet og kostnader?

Lean

1. Har du jobbet med bruk av Lean-filosofi/Construction før? Hvis ja, hvor lenge?
2. Blir det i dag brukt metoder innenfor Lean i prosjektet du arbeider med?
   a. Hvilke fordeler/utfordringer ser du ved bruk av denne metoden?
   b. Har bruken av denne metoden effektivisert prosjektet? Hvis ja, i hvilken grad?
3. Har du gjennom prosjektet fått noen form for opplæring eller kursing i Lean Construction?
4. Hvilke hovedargumenter vil du si er suksessfaktorene for en vellykket implementering av Lean Construction i en bedrift?
5. Hva vil du selv si er de viktigste barrierene for vellykket implementering av Lean Construction i en bedrift?
6. Hvilke fordeler mener du Lean Construction tilbyr?
7. Hvordan er holdningene rundt bruken av Lean Construction der du jobber?
   a. Blir det faktisk implementert?
   b. Er kunnskapsnivået høyt nok hos de fleste?
8. Prefabrikasjon av elementer er en Lean-metode og krever et godt samarbeid. Hva er dine tanker rundt det?
9. Oppgaven er vinklet mot prefabrikkerte elementer, da det er en Lean løsning. Det er mange aktører i bransjen som foretrekker stedstøpt, hvorfor mener du det er sånn? Er ikke prefab bedre med tanke på tid og kostnader hvis det er et godt samarbeid mellom entreprenør og leverandør?
10. Har du tips til hvordan jeg kan gå frem med å svare på oppgaven? Jeg har nå skrevet teoridelen hvor jeg snakker om Lean og Last planner system, også skrevet om betong, prefab og stedstøpt metodene. Når det kommer til valg av løsning for referanseprosjektene, hva må jeg tenke på?