Towards Effective Planning and Control of Complex EPC Construction Projects

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Preface

As I stand on the cusp of completing my master's degree at TU Delft, I am filled with a mix of excitement and gratitude. Excitement for the opportunities and challenges that lie ahead, and gratitude for the support and guidance of my esteemed supervisors and committee members, as well as my colleagues and loved ones.

When I first embarked on this journey more than two years ago, I had no idea what to expect. I had been out of school for over a decade, and the prospect of returning to academia was both daunting and exhilarating. But I knew that I wanted to challenge myself, to push the boundaries of my knowledge and skill and to make a meaningful contribution to my field.

I am deeply grateful to Hans, the chair of my graduation committee, for his unwavering support and guidance throughout this process. His expertise and critical insights have been invaluable to me. I would also like to express my sincere appreciation to Afshin, my first supervisor, for his patience, encouragement, and guidance. His guidance helped shape the direction of my research, and I am deeply thankful for his support. I would also like to thank John for his invaluable insights and feedback, which have helped me to refine and improve my work. And finally, I would like to express my sincere gratitude to Duncan, my company supervisor, for his extreme efforts throughout this process. His expertise and guidance have been instrumental in my development as a professional, and I am deeply grateful for his support.

But most of all, I am grateful to my family - my mother, stepfather, daughter, and son - for their love and support throughout this journey. They have been my rock, my support system, and my biggest fans, and I could not have made it to this point without them. I will always be grateful to my friends and colleagues at Arcadis DPS Group for their constant support and encouragement.

Over the past more than six months, I have poured my heart and soul into my master's thesis, which I began preparing in April and completed in December. The process was challenging at times, but it was also deeply rewarding. I have learned so much about the latest management methods and techniques, and I have had the opportunity to work on a truly exciting and innovative project.

As I look to the future, I am excited to see where my studies will take me. The field of project management is constantly evolving, with new technologies and methodologies emerging all the time. I am eager to continue learning and growing in this field and to make a meaningful contribution to the ongoing conversation about the management of engineering projects.

Jinghua Ning
Delft, December 2022

Executive Summary

Abstract

Effective planning and control are crucial for the successful delivery of engineering, procurement, and construction (EPC) projects, which are characterized by complex organizational structures, interdependent activities, overlapping phases, and a large number of disciplines and participants. However, project uncertainty, including the lack of complete information and frequent changes, can lead to delays and cost overruns if not effectively managed. In this research, an integrated planning and control approach for EPC projects that addresses these challenges by combining the Last Planner System of Lean Construction and the Scrum framework of Agile Management is developed. Through a literature review and a case study of an EPC industrial construction project, six requirements for effective planning and control and mechanisms for their implementation are identified. The approach is evaluated through interviews with industry experts. The results highlight the importance of both structured planning and control for identifiable and predictable uncertainties, and flexibility and agility for unforeseen uncertainties, in managing project uncertainty in EPC projects.

Keywords: Planning and control, EPC construction project, complex, uncertainty, Last Planner System, Scrum

Research Problem

The interdependence of activities, overlapping phases, large number of disciplines, and number of participants in EPC industrial construction projects result in fragmentation of issues, dynamic and complex organizational structures, lack of complete information, and frequent changes, which exacerbate the challenge posed by project uncertainty. If project uncertainty is not effectively managed, the project delivery process will result in delays that may lead to cost overruns and revenue shortfalls. Therefore, this research considers uncertainty as a key focus of planning and control strategies for EPC industrial construction projects.

The main research question answered in this research is,
How to effectively plan and control complex EPC industrial construction projects?

Methodology

The research adopts the Scientific Design Research Cycle to lead the research process and develop the research outcome. The literature review provides a deep understanding of the research problem in the EPC construction project environment and extracts requirements for innovative solutions in this environment from a review of existing technical solutions in the industry. A case study of an EPC industrial construction project observes and analyses these requirements and associated technologies, providing practical knowledge for the development of the final solution. With the input of theoretical and practical knowledge, the main outcome of the research, an integrated planning and control approach is developed under the design science research method.

Results and recommendations

The literature review and case study conducted in this research identified six requirements for effective planning and control, and mechanisms for their implementation using technical tools such as the Last Planner System of Lean Construction and the Scrum framework of Agile Management. The proposed approach was evaluated through interviews with industry experts, who provided insights on its applicability and effectiveness in the EPC construction industry.

The results of this research highlight the importance of structured planning and control for addressing identifiable and predictable uncertainties, which can be addressed with systematic and disciplined methods such as the Last Planner System. At the same time, the research also highlights the need for flexibility and agility in dealing with unforeseen uncertainties, which can be addressed by agile and adaptive approaches such as the Scrum framework. By combining structured and agile approaches, it is possible to effectively manage the complexity and uncertainty inherent in EPC projects and deliver them successfully.

This research contributes to the body of knowledge on the management of EPC projects and provides practical recommendations for practitioners and researchers in the field. Further research is needed to validate the proposed approach in different contexts and with different types of EPC projects, and to explore the potential of using advanced tools and techniques.

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Abbreviations

APM	Agile Project Management
BOD	Basic of Design
CPM	Critical Path Method
C	Construction stage
CC	Critical Chain
CE	Concurrent Engineering
CMT	Construction Management Team
DSR	Design Science Research
DSRC	Design Science Research Cycle
E	Engineering stage
EPC	Engineering Procurement and Construction
EVM	Earn Value Method
IT	Information Technology
LC	Lean Construction
LPS	Last Planner System
P	Procurement stage
PAR	Pre-Assembled Pipe Racks
PERT	Program Evaluation and Review Technique
PMI	Project Management Institute
PMBOK	Project management body of knowledge

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Introduction

In this chapter, Section 1.1 provides the research problem statement. Section 1.2 describes the research objectives. Based on the research objectives the main research question and 4 sub-questions are formulated and described in Section 1.3, followed by the structure of the report in 1.4.

1.1 Research Problem Statement

To overcome the shortcomings of the traditional design-bid-build (DBB) project delivery method, the construction industry has transitioned to a more integrated form of project delivery (Poudel et al., 2020). Engineering, Procurement, and Construction Contract (EPC) is a form of integrated project delivery in which the owner contracts with a single contractor to carry out engineering design, procurement, and construction (Hale et al., 2009). This project delivery method has gained popularity in industrial sectors that often involve plant and equipment because it reduces costs and saves time by promoting collaboration between designers and contractors. (Hale et al., 2009; Putro & Latief, 2020). EPC contracts are inherently riskier than traditional Design-Bid-Build contracts (Rehman & Shafiq, 2022).

EPC construction projects face a number of challenges by increasing complexity and dynamism. EPC industrial construction projects are complex due to integrated different activities of different stages, EPC industrial construction projects are complex as a result of the integration of multiple activities at various phases, the management of interfaces between the project's stakeholders, and the specialized needs of distinct industrial sectors (Rehman & Shafiq, 2022). However, despite these challenges, the management of major construction projects has not improved considerably (Rehman & Shafiq, 2022). However, despite these challenges, the management of construction projects has not improved considerably.

Project management approach has become an important factor in the successful delivery of projects (Chin et al., 2012), and project planning and control are important factors contributing to the performance of EPC projects (Kabirifar & Mojtahedi, 2019). The planning and control approach widely used in the construction industry is based on the traditional management concept of "linear and predictable project planning practices" and "management as planning" (Lee et al., 2006; Koskela & Howell, 2001). However, this technique, based on the assumption that goals can be defined based on long-term predictions of requirements and productivity, and that controls monitor compliance with these goals, is only relevant to low-complexity projects (Johnston & Brennan, 1996). Construction Projects are facing the challenges of increasing complexity and dynamism, and traditional project management methods no longer guarantee effective control of desired results (Sohi et al., 2016). EPC projects are still reported to have many delays and other shortcomings in practice, which create barriers to continuity in project implementation and create uncertainty about the achievement of project objectives (Khalfan & Ghaithi, 2014). Studies based on EPC project case studies showed that the main factors leading to schedule delays and cost overruns were mostly related to project complexity, aggressive unrealistic schedules, weak or poor planning and control (Akhtar, 2020). The traditional methodology of plan and control the delivery of complex EPC projects need to be updated.

In the search for new approaches that can cope with highly complex construction projects, a variety of new management concepts such as the Lean Construction (LC) and Agile Project Management (APM) have been followed and applied in the construction industry (Amor et al., 2003). The use of these foundational concepts has greatly influenced the character and purpose of planning and control techniques (Amor et al., 2003).

However, many planning and control strategies and methodologies concentrate on resolving a single problem rather than providing assistance for project-wide planning, scheduling, and control (Dallasega et al., 2021). The majority of the literature on planning and controlling EPC contract projects concentrates on specific project stages such as engineering design (Hung et al., 2008; Kalsaas et al., 2016; Sriprasert & Dawood, 2002; Wesz et al., 2018) , procurement stage (Christopher & Towill, 2001; Yeo & Ning, 2002), construction production stage (A Khalfan, 2005; Salama et al., 2021; Sriprasert & Dawood, 2002), and commissioning stage (Power et al., 2021). It is increasingly believed that today pure project management methodologies are no longer effective (Hertogh & Westerveld, 2010; Priemus & van Wee, 2013). Sohi et al., (2016) found that the combined usage of Lean and Agile approaches can handle project complexity and suggested that project management methodologies must be tailored to the size, uniqueness, and complexity of projects in order to successfully deliver complex projects.

1.2 Research Objectives

The aim of this research is to develop an integrated planning and control approach for EPC construction projects to address the complexity and uncertainty challenges effectively. The results of this research will provide valuable insights for managers and practitioners working on EPC projects and contribute to the development of more effective planning and control approaches for these complex and uncertain endeavors.

The following objectives are used to achieve the aim of this research:

- To conduct an analysis of EPC projects and the challenges they face, with a focus on complexity and uncertainty

- To identify requirements for planning and control that can effectively planning and controlling EPC construction projects
- To identify mechanisms and techniques by which the identified requirements can be applied to EPC industrial construction projects
- To identify the applicability of the proposed solution in industry

1.3 Research Question

Analysis of the context, the definition of the problem statement and establishment of the research objectives led to the main research question:

How to effectively plan and control complex EPC industrial construction projects?

In order to arrive at an answer to the main question, the following sub-questions need to be answered.

Sub-question 1: What are the challenges of the planning and control in the complex EPC industrial construction project?

Sub-question 2: What are the requirements related to planning and control approaches to address the challenges of EPC construction projects in the existing academic literature?

Sub-question 3: How can these identified requirements be effectively implemented in an EPC industrial construction project?

Sub-question 4: How can an integrated planning and control approach be developed?

1.4 Report Structure

The research is divided into nine chapters, as shown in Figure 1.
Chapter 1 is the introductory chapter, which gives the research topic, the research objectives, the specific research questions, and the structure of the report. Chapter 2

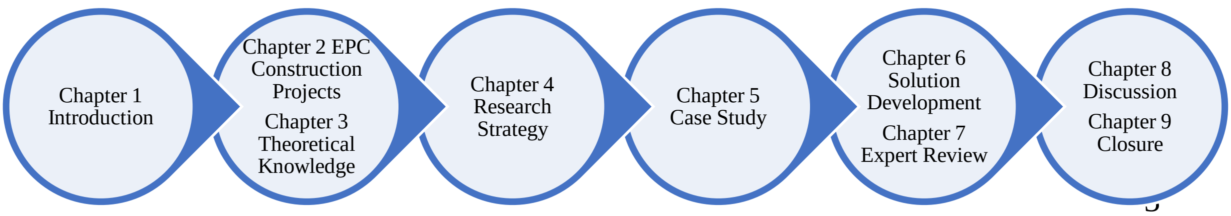


Figure 1.The structure of the report

analyzes the challenges of planning and controlling EPC construction projects. Chapter 3 extracts requirements that can be used to develop an integrated planning and control approach for EPC construction projects by reviewing existing planning and control technologies. Chapter 4 develops the research strategy based on the objectives and questions of the research. Chapter 5 utilizes case study to further understand the relevance of the research problem and identifies mechanisms and techniques for effectively implementation of the requirements. Chapter 6 describes the development and the result of the proposed solution. Chapter 7 evaluates the results through the expert review. Chapter 8 discusses the findings of the research and Chapter 9 provides answers and a summary of the research questions and provides recommendations.

Phase 1 Literature Review

Phase 1 uses the literature to provide the analysis of the environment of the research problem, and a review of the theoretical knowledge that supports this research and establishes the initial requirements. This phase answers sub-questions 1, 2.

Chapter 2
Sub-question 1 What are the challenges of the planning and control in the complex EPC industrial construction project?

Chapter 3
Sub-question 2 What are the requirements related to planning and control approaches to address the challenges of complexity and uncertainty associated with EPC construction projects in the existing academic literature?

2. EPC Construction Project Challenges

In this chapter, an understanding of the execution activities of EPC construction projects (2.1) and the challenges posed by the complexity of such projects (2.2) is presented through a literature review to complete the investigation of the application context of the problem.

2.1 EPC construction project activities

Within the scope of this research, it is considered that the owner awarded a turnkey contract to the EPC general contractor, who is responsible for undertakes the design, procurement, construction of the project, and the quality, safety, schedule and cost of the entire project (Qin, 2017). The main stages of a general contractor executing an EPC project is Engineering stage, Procurement stage, Construction stage. The activities and characteristics of each stage are described below.

2.1.1 Engineering

Engineering (E) is the process of defining, quantifying and qualifying the owner's needs, wants and desires and translating them into clear criteria to be communicated to the contractor (AlMarar, 2019). Numerous studies have emphasized the crucial relevance of design and planning at the beginning of a project since decisions taken during the engineering phase will result in the commitment of substantial amounts of money and other resources necessary to properly implement and complete the project (Bakker & de Kleijn, 2014; Qin, 2017; Rehman & Shafiq, 2022). In addition, engineering design considered pivotal in the performance of EPC projects, and this importance followed by the construction phase (Habibi et al., 2019). Typically, the design of an engineering system involves a sequence of processes, including conceptual design, preliminary design/basic design, and detailed design.

The nature of the engineering stage’s design activities distinguishes it from the other stages. The manifestations of its specificity can be summarized as follows (Kalsaas et al., 2016; Wesz et al., 2018).

- There is a great deal more unpredictability and variability in design: the client's needs are difficult to specify, and certain judgments must be made without complete information.
- In the early stages of design, the designer's attention oscillates between comprehending the problem and finding a solution.
- Design work tends to expand to fill the available time.
- There are complicated interdependencies between different disciplines in design.

2.1.2 Procurement

The engineering stage is followed by the procurement (P) stage. The primary activities associated with procurement are known as sourcing, purchasing, contracting, and on-site materials management. Yeo & Ning (2002) argued that the importance of procurement lies in the fact that: the materials procured are the basis for construction the facility; the cost of materials represents a major part of the total cost of an EPC project; when compared to engineering and construction, especially when it comes to outsourcing and subcontracting, the level of control is lower; moreover, the manufacturing of capital equipment is time-consuming and expensive. The research of Hatmoko & Khasani, (2019) found that delays in long lead time items were one of the most significant risk factors contributing to EPC project delays, and therefore successful procurement management could lead to better cost and delivery results for the overall project.

2.1.3 Construction

The construction (C) stage is the activity of construction or constructing the facilities as efficiently as possible, based on everything decided in the engineering stage. The contractor begins construction of facilities available during the construction stage based on the work packages developed during the engineering stage, using equipment and materials from the procurement stage (Yeo & Ning, 2002). The categories of the construction stage itself include different disciplines such as civil, mechanical, plumbing, electrical and instrumentation. These disciplines follow a system to facilitate planning, execution, monitoring and control during construction. One of the characteristics of the C stage is the large number of subcontractors and stakeholders involved depending on the size and function of the project, and another is that site activities are often affected by unpredictable events such as adverse weather conditions or changes caused by supply chain or other factors, such as unsynchronized trade as well as work site accidents, which require frequent changes and updates to the construction schedule (Dallasega et al., 2021) .

2.2 Complexity of EPC industrial construction projects

Project complexity is a multidimensional concept involving different levels of uncertainty or different categories of complexity (Geraldi et al., 2011) Rezende & Blackwell, 2019). The activities of construction projects are not only diverse and complex, but they are also highly interdependent, each stage of the engineering, procurement, and construction of an EPC construction project exists independently as a complex project management process, but these three stages are also interdependent and interact with each other. Moreover, industrial construction projects are comprised of two distinct, highly interdependent subprojects relating to industrial output and building (van der Velde & van Donk, 2002), involving not only the work of the civil engineering profession, but especially a large number of professions related to industrial equipment and machinery. These intricate dependencies increase the risk of project schedule and budget overruns, making the management of the relationships and interactions between project activities crucial.

These interdependent activities constitute an intricate system of human activities, so the complexity of the project also comes to involve the number of people and stakeholders involved and their interactions (P. E. Eriksson et al., 2017). The vast number of participants in a project causes fragmentation, with participants always transferring information back and forth, and the possibility for hostile relationships across organizations as a result of the fragmentation of work (Yeo & Ning, 2002) . Eriksson et al. (2017) argued that complex construction projects are cross-organizational and that the highly interdependent tasks of different participants must be carefully coordinated; hence, project participants must collaborate in issue solving and decision making.

The project uncertainty is the critical factor that cause project delay and failure. Uncertainty reduces reliability and thus introduces variability in the construction process (Lindhard & Wandahl, 2015). As it is clear from the previous information about the characteristics of the different activities in an EPC project, variability is unavoidable in complex construction projects and therefore "project participants need to define as they go, adjusting as the project unfolds" (Pollack, 2007: p. 271).

2.3 Summary of Chapter 2

In summary of chapter 2, the interdependence of activities, overlapping stages, large number of disciplines, and number of participants in EPC industrial construction projects result in fragmentation of issues, dynamic and complex organizational structures, lack of complete information, and frequent changes, which exacerbate the challenge posed by project uncertainty. If project uncertainties are not effectively addressed and dealt with, they can eventually negatively affect at least one project objective (PMI, 2021). For example, the results of the engineering stage of an EPC industrial construction project do not accurately guide the execution of the project, leading to delays in the delivery of engineering deliverables and material and equipment because, as Flyvbjerg, (2013: p. 11) noted, "delay is a key issue in complex projects because it can lead to cost overruns and revenue shortfalls." These delays will lead to low construction productivity, the occurrence of waste and rework, and increased fixed and variable costs of the project. In addition, delays will delay the use of industrial facilities, which will result in delayed revenues for the owner. Therefore, complexity and uncertainty are the key focus for EPC industrial construction project planning and control strategies within the scope of this research.

3. Theoretical Knowledge

3.1 Existing planning and control methods

3.1.1 Traditional Techniques

In a typical planning system, plan generation, revision, and execution are the most important management tasks during the early stages of a project, when planning occurs (Cooke & Williams, 2013), it is the so-called 'management-as-planning' approach. This approach breaks down the project into manageable activities in the form of a work breakdown structure (WBS) to represent the technical and implementation dependencies between project activities, linked by priority relationships (Pellerin & Perrier, 2019). The most researched uncertainty in this management paradigm is the stochastic character of activity time, which is deterministic and statistically described, and is frequently addressed using the critical path method (Ballard et al., 2020).

Critical Path Method (CPM)**,** which uses the basic concepts of the Project Management Body of Knowledge (PMBOK), has been used in the construction industry since the late 1950s (Dallasega et al., 2021). CPM is a network-based approach where activities and the links between them are considered as time-related modelling elements (Hajdu, 1997). CMP supports the identification of critical paths, where a delay in one of the activities leads to an overall project (Dallasega et al., 2021). The time required to execute each activity is estimated based on the level of resources (human, mechanical, etc.) required for each activity and simply assumes that resources are available when needed and therefore the planned activities are doable (Pellerin & Perrier, 2019).

However, this traditional technique appears to be better suited for less complex environments than for large, complex projects with limited predictability and high impact changes. Traditional prediction and control approaches focus heavily on planning and control and aim to mitigate or eliminate uncertainty and complexity. The accumulation of delays in the sequence of activities depends on the safety time and the use of buffers in CPM (Alsehaimi et al., 2014). Herroelen et al. (2002) claimed that adding a time buffer to the critical chain may result in excessively long project completion dates and may not prevent the spread of uncertainty throughout the plan. This is because it only considers time and priority constraints between activities that are not taken into account (Shi & Deng, 2000) and ignores non-priority constraints, such as the variability of construction works resulting from the interaction between project variables (such as space or resources) and various execution methods (Alzraiee et al., 2015). The outcomes or probabilities of some of these changes are not fully understood (Martinsuo et al., 2014), therefore it is difficult to predict and quantify this uncertainty, making it challenging to manage with conventional management techniques. As a result, workflow performance during the execution of construction projects becomes extremely irregular, resulting in a failure to execute precisely as intended and the introduction of rework and waste (Dallasega et al., 2021).

Furthermore, the traditional approach is to manage changes passively after they have occurred (Hällgren & Maaninen-Olsson, 2005; Petit & Hobbs, 2010). According to Seppänen & Aalto (2005) the discovery of deviations in CPM frequently takes place at an inappropriately late stage. In addition, this type of reactive management has a tendency to result in an excessive reliance on deterministic planning, in which all significant decisions are decided in advance, and revenues are assumed to remain unchanged (Ballard et al., 2020). CPM is conceived of in terms of "management as planning," which means that management actions do not help the execution of preventative measures because they only take place in the event of deviations from the plan (Dallasega et al., 2021). According to Menesi & Hegazy (2011), CPM does not support the execution of corrective measures to recover from challenges relating to implementation.

The most common method for addressing the uncertainty of activity time and resource requirements is by modeling for probabilistic analysis. Techniques such as the Program Evaluation and Review Technique (PERT), the Monte Carlo simulation, and the process simulation are examples of well-known techniques (Amor et al., 2003). In terms of modeling, the difficulties of modeling and solving a complex stochastic dynamic planning problem are described by Jørgensen & Wallace (2000). Ballard et al. (2020) argued that these difficulties lead some simulation models (Deblaere et al., 2011; Vaagen et al., 2018) to be unsuitable for flexible handling of change, some of them can only compare one solution with others, cannot account for the optimality of a solution, and are therefore less suitable for conceptual analysis of how to develop flexibility or are only suitable for small problem instances.

3.1.2 Innovative Techniques

In the traditional management paradigm, the use of simulations and buffers to cope with uncertainty can be seen to be limited, as there are four different levels of uncertainty in projects: variation, foreseeable uncertainty, unforeseeable uncertainty, and chaos (Pich et al., 2002), each type requiring a different approach to planning and control. Recent studies have demonstrated that to successfully handle changes that are unavoidable in a project, more flexible approaches are required rather than advanced planning and control (Gransberg et al., 2013; Koppenjan et al., 2011). According to A. Eriksson et al. (2017), in order to successfully manage complex projects, one must employ flexibility-centered project management methods. These practices involve a number of different activities, including collaboration, exploratory learning, and adaptability. These concepts increasingly point to general management procedures that are related with the development of trust, perception, and organizational learning

(Atkinson et al., 2006).

On the other hand, Ballard et al. (2020) claimed that behavioral barriers arise when simulation models and formal control systems are replaced by team coordination and judgment procedures without any reduction in problem complexity. A degree of behavioral stability can be ensured in human-centered decision-making processes by using simulation and formal management procedures that aim to eliminate or reduce the various heuristics that lead to bias (ibid.). Flexibility requires structure: bias can be eliminated or reduced through structure (Jalali Sohi, 2018.). Therefore, many studies have emphasized the importance of maintaining a healthy balance between formal management systems and informal processes (Atkinson et al., 2006; Osipova & Eriksson, 2013; Poppo & Zenger, 2002). According to B. Jørgensen & Messner (2009), formal management processes make it possible for employees to deal more successfully with work processes and unavoidable changes, which makes it easier for employees to overcome uncertainties, barriers, and risks.

Lean Construction (LC) and Agile Project Management (APM) are modern management concepts that differ from traditional project management in that they encompass innovative solutions to complex projects not found in the traditional paradigm.

Lean Construction (LC), a concept derived from the Toyota Lean Production System, focuses not only on conversion processes but also on the management of flow and value (Amor et al., 2003), and it considers well-designed processes as both technical and social, with credible commitment as the social glue (G. Ballard, 2000; H. G. Ballard, 2000). The main goal of LC is to understand the physics of production at the task level and then to design support systems and requires a balance between formal and less formal management and control processes that minimize the combined effects of dependencies and changes between activities (Howell, 1999). In this research, Last Planner system for planning and control (G. Ballard, 2021), the core of lean construction, will be reviewed.

In contrast, the APM considers that the future is unpredictable. It replaces upfront planning with incremental planning based on the latest available information and addresses technical risks early in the process to reduce the impact of changing requirements and provide regular and ongoing business value to the organization (Sohi et al., 2016). It also empowers and empowers employees, encourages continuous communication between business areas and project team members, and increases customer engagement (Jalali Sohi, 2018). Proponents of Agile see it as a more flexible approach than traditional methods, with the ability to incorporate methods that deal with all changes (Ribeiro & Fernandes, 2010). In this research, to follow the guidelines of the most widely used and popular agile methods, we chose Scrum.

3.1.2.1 Last Planner System

The idea of Last Planner System (LPS) originated from the need for production control with a strategy to improve workflow predictability by controlling the quality of tasks in weekly work schedules and by improving the predictability of work schedules (Ballard 1994). However, over time, LPS has outgrown its initial production control function (Ballard and Tommelein 2016). The current LPS benchmark (G. Ballard & Tommelein, 2021) further extends LPS in principle to production (i.e., working toward goals) and project planning and control (i.e., setting goals).

Ballard (2020) argues that the planning process for LPS deferral strategies embodies a planning flexibility. This is very different from traditional project management, where LPS follows the rule that plans should be refined based on information emerging from production and become more detailed as execution time approaches, whereas in traditional project management, what should be done is defined in the long-term plan and released directly to the execution process (Koskela and Howell 2002). It has been demonstrated that this technique is superior at adapting to changes, particularly those that are foreseeable and quantifiable (G. Ballard, 2000; G Ballard & Tommelein, 2016; Alsehaimi et al., 2014).

In addition, the flexibility of LPS is reflected in its reactive adaptation to change. LPS shields the variability of production work by refining plans and continuously addressing constraints based on the latest information provided by all parties, a process that not only facilitates a collaborative environment but also increases the efficiency of the project workflow (Ballard et al., 2020). Eriksson et al. (2017) point out, based on empirical data statistics, that collaboration is a central enabler of increased adaptability, and that increased adaptability improves the practical performance of projects. A collaborative culture promotes communication and knowledge of each participant's capabilities to prevent information deficits. According to Cook (2001), "trust" can be raised, and uncertainty can be minimized, if one is aware of the talents possessed by other workers. According to Atkinson et al. (2006), trust is the most cost-effective method of bridging the information deficit gap. They also emphasized that the linkages and dynamics between uncertainty, control, and trust are improved when "trust" is factored into the process of managing uncertainty. Trust is the most cost-effective method of bridging the information deficit gap.

According to Perminova et al. (2008), the two most important aspects of effectively managing uncertainty are reflective learning and sense-making. These two aspects serve as enablers for achieving flexibility and speed in decision-making when it comes to selecting alternative actions based on the circumstances. LPS emphasizes learning from failures, and it argues that standard deviations may not be known, in which case one should learn from experience and adjust accordingly (Ballard & Tommelein, 2021). Although reflective learning and sense-making use organizational judgment processes that depend on individual skills, intuition, and judgment (Perminova et al., 2008), and as previously analyzed, there are behavioral challenges from people, standardized and modular processes and procedures form the necessary foundation to support reflective processes. LPS creates a rhythmic mechanism that supports standardized management of reflective behavior.

In the construction industry, LPS is task-based and therefore it is proven for application in managing the construction stage of production, however, due to the non-sequential/iterative nature of design, there is a greater degree of uncertainty than in the construction stage (Ballard et al., 2020). Although case studies on the use of LPS in the design process have shown increased reliability in planning and reduced variability in workflow, challenges remain in the implementation of LPS in design, with difficulties identified in one case study in the implementation of medium-term plans in the design process (Wesz et al., 2018). The need to take responsibility for engineering design in EPC industrial construction projects and the challenge schedules has led to the suggestion that some adjustments to the LPS to bridge this gap. In the latest research on how to adapt the use of LPS in the design process, Ballard et al. (2020) recommend the use of tools such as Agile and Scrum to track tasks and progress, believing that Lean and Agile are a classic combination made even better with the help of design thinking.

Ballard et al. (2020) noted that proactively responding to change within specified time and cost limitations is challenging if flexibility is not incorporated into the overall management strategy. They proposed a process for producing a project execution plan that includes pull planning, risk assessment and mitigation, and a component process for incorporating options into the project milestone schedule. The key to successfully producing this schedule is to get those subject matter experts and decision makers to work together to develop a sequence of activities that produces an acceptable workflow to meet project milestones and other objectives.

In conclusion, while LPS requires more flexible adaptation in the design process, LPS has been proven to handle workflow and inevitable changes in a more effective manner through a hierarchical, collaborative, and reflective learning planning and control process (Jørgensen & Messner, 2009;Ballard & Tommelein, 2021). When LPS is extended to create a logical network at the strategic planning level of a project that matches the feasible time for project delivery, it is believed that the performance of projects executed under uncertainty can be improved (Ballard et al., 2020).

3.1.2.2 Scrum

Scrum is an agile process framework for managing complex product development projects with high levels of uncertainty (Poudel et al., 2020). Scrum builds on empirical process control theory and uses iterative and incremental approaches to optimize predictability and manage project risk, making the product development process more efficient and reducing time-to-market practices with the ultimate goal of supporting project teams to deliver the highest value products (Poudel et al., 2020; Cervone, 2011). Scrum was introduced by Sutherland and Schwabe in 1995, and the latest version of the official Scrum guide was released in November 2020 (Hron & Obwegeser, 2022).

Scrum is built on empiricism and lean thinking and uses three basic concepts of transparency, inspection and adaptation in its implementation, which are realized through Scrum's iterative process, artifacts and roles (Schwaber & Sutherland, 2020). Scrum is a lightweight framework that defines only the parts needed to implement the theory, and within which various processes, techniques, and methods can be employed. Appendix A2 shows the Scrum framework as described by Poudel et al. (2020).

Scrum is commonly used in information technology (IT) projects, and it has been shown to increase the productivity of IT projects, ultimately producing good results such as increased customer satisfaction, improved product and process quality, and reduced costs (Cardozo et al., 2010; Caballero et al., 2011). Some of the important advantages of using Scrum in construction projects compared to traditional methods are fewer processes (22% reduction), less documentation (43% reduction), less execution time due to overlapping activities, no increase in resource use (multidisciplinary, 67% reduction), fewer roles and resources, and lower costs (Luis et al., 2020).

Scrum needs to adapt or enhance different aspects of the methodology to the environment of the construction industry. By comparing Scrum with traditional methodologies, Luis et al. (2020) suggested that due to the complexity and limitations of the SCRUM methodology, it should not be used as a substitute for traditional methodologies, but rather a blend of classical and participatory, collaborative, and agile concepts to form a so-called "pseudo-agile" approach. Lia et al. (2014) recommended integrating LPS, Scrum, and Critical Chain to increase the predictability of the delivery of complex engineering projects. According to Kalsaas et al. (2016), employing Scrum to establish short milestones and iterations allows for proactive design stage change management. G. Ballard & Tommelein (2021) and Poudel et al. (2020) hypothesized that the combination of Scrum and LPS might enhance the performance of LPS Based on a comprehensive comparison and critical assessment of LPS and Scrum by Poudel et al. (2020) (see Appendix C), it was determined that many components of Scrum already exist in LPS in the same or similar form, and hence it is possible to explore extending LPS with Scrum best practices. The authors identified four main Scrum elements that can be used to improve the LPS benchmarks, where implementing the concept of Scrum increments, especially when using LPS in the design stage, helps to deal with the increased uncertainty, speed, and complexity inherent to the iterative design process.

3.2 Requirements Identified in the Literature Review

Due to the differences in the size, uniqueness, and complexity of the projects and therefore the need for tailored management approaches (Sohi et al., 2016). Lean construction has been suggested as one of the approaches that can be integrated with agile to manage construction projects. By combining Lean and Agile methods, waste in the construction sector can be avoided, making projects more profitable, efficient, and flexible (Jethva & Skibniewski, 2022). Based on the discussion of the various planning and control techniques and the challenges of uncertainty posed by the complexity of EPC industrial construction projects, the following requirements can be summarized to enhance the effectiveness of planning and control on EPC industrial construction projects. Table 1 contains a summary of the specifications.

These requirements can be considered as the starting point for the case studies conducted in this research. These requirements are derived from different types of studies, both case studies and exploratory studies, and although most of the studies are from the construction industry, the body of knowledge on planning and control systems applied at different stages in different types of projects is fragmented. Considering the unique characteristics of each construction project, there is a need to further refine the mechanisms of these requirements in practice in EPC projects in case studies, and to consider the possible interactions between different requirements to complete the design artifacts.

Table 1 Requirements for effectively planning and control identified from the literature

Requirements from the literature	Description
Multi-level Planning and Control	The efficient management of anticipated and statistically estimable changes requires the creation of various levels of planning and control. Planning must be refined depending on information that emerges throughout the process, with more specific plans as the time for task execution gets closer. (Ballard & Tommelein, 2021).
Collaboration Planning	Facilitate effective information exchange through cooperation between different participants. The collaborative process can also facilitate the integration of different levels of planning and control objectives and avoid overly centralized decision making, which increases "trust" and reduces uncertainty (Viana et al., 2022). In addition, collaboration is positively related to explorative learning (P. E. Eriksson et al., 2017).
Effective management of constraints	Timely and comprehensive proactive identification of potential changes and constraints and the absorption of these uncertainties by inserting appropriate buffering strategies in the project plan to shield all variables affecting task initiation and completion, thus eliminating waste (Wang et al., 2016). This is related to managing expected uncertainty, i.e., related to control (Floricel & Miller, 2001).
Providing adaptation	Responding to new situations and meeting new needs as they arise requires reactive adaptation, such as modifying plans, technical solutions, and/or production processes (Dallasega et al., 2021). Adaptation is positively correlated with time performance, i.e., it can improve the time performance of a project (Eriksson et al., 2017b).Adaptation is related to coping with unforeseen uncertainties and contingencies and is a core characteristic of flexible project management (Crawford & Pollack, 2004; Karrbom Gustavsson & Hallin, 2014).
Provide opportunities for learning	Exploratory and reflective learning is associated with flexibility and rapid handling of uncertainty and unforeseen changes. Regular exploratory and reflective learning is positively correlated with adaptation and can improve the ability to generate and adopt new technologies/solutions when needed (P. E. Eriksson et al., 2017).
Increase transparency	Increased transparency is associated with the availability of information and cooperation. Transparency allows work to be performed more effectively, efficiently, and safely, promotes trust, and stimulates further communication among process participants (Brady et al., 2018).

3.4 Literature review Summary

The characteristics of EPC industrial construction projects and their complexity pose challenges for their planning and control, with different levels of uncertainty in the overlapping and dependent stages of the three different characteristics, and these require different coping strategies. The literature reviews three main techniques for dealing with uncertainty. Traditional methods that rely on buffers are difficult to accurately predict uncertainty and cope with unpredictable changes, and this "management-as-planning" approach has limited effectiveness in the face of complex and dynamic construction projects. Simulation techniques are not well suited to the development of flexibility and are not suitable for large and complex construction projects. Lean construction and agile management methods are gaining attention as modern and innovative management methods that have proven to be effective in managing complex projects with uncertainty. The principles and mechanisms for managing uncertainty of LPS and Scrum are analyzed in the literature review, and the requirements for effective planning and control of complex EPC industrial construction projects with different levels of uncertainty are summarized and briefly described in the context of relevant theoretical literature. These requirements will be observed and analyzed in the case study in the next chapter to understand their practical relevance in a given context. The Literature summary can be found in table 2.

Table 2. Literature Summary

Literature area	Key findings	Understanding	Outcome
EPC industrial construction project	The different characteristics and dependencies of the three stages lead to different levels of uncertainty in the project.	Need: different coping strategies	Requirements for effectively planning and control of EPC construction projects
Different planning and control techniques	• CPM from traditional is often assumed that plans are mostly feasible, and uncertainty and interdependence are not fully recognized • LPS from LC provides a systematic approach to project planning and control that focuses on maximizing value and minimizing waste • Scrum from APM offers a flexible and adaptable framework for managing complex projects	• CPM limited effectiveness in the face of complex • Combination LPS and Scum is a potential solution to address the problem	

4. Research Strategy

This chapter develops the research strategy. Section 4.1 introduces the methodology applied in this thesis. Research process is in 4.2. The scope of this research is defined in section 4.3.

4.1 Research Methodology

Through the understanding of the main research questions in Chapter 2, there is a need to support the solution of problems that exist in a specific environment (EPC construction project) using effective knowledge (planning and control methods). According to Saunders & Thornhill (2009), the goal of Design Science Research (DSR) is to develop an artifact that supports the understanding and resolution of problems in a given environment through the use of validated knowledge, which is the research methodology for this research. Rocha et al. (2012) considered DSR as an appropriate method for conducting construction management research, which the goal is to develop an artefact that supports problems in a particular context to be understood and solved using valid knowledge. According to van Aken, (2004), DSR must provide a theoretical contribution to the current body of knowledge, constructive research will better connect research and practice, thus enhancing the relevance of construction management scholarship.

The artifact in this research is formed by applying the three design science research cycles (DSRC) proposed by Hevner (2007), as shown in Figure 2. The relevance cycle involves the environment of the applications to be considered for the designed artefacts, providing the requirements for the design research and the real-world context for the artefacts to be evaluated. Chapter 2 of this research constitutes the input to the relevance cycle: the activity characteristics and complexity challenges of EPC construction projects are presented as requirements for designing artifacts; while the application domain of the artifacts, including the target audience (general contractor), the technical domain (LC and APM planning and control techniques), and the organizational domain (industrial construction sector) serve as the scope of this research.

The rigor cycle provides the existing knowledge for the research, and the knowledge base for this research is developed through a combination of theoretical and practical knowledge. Theoretical knowledge is formed through literature review (Chapter 3) and practical knowledge is formed through case studies (Chapter 5). Due to the time-constrained nature of the master's thesis research, approach validation cannot be subject of action research or field application evaluation. Therefore, this research focuses on the creation of design knowledge, i.e., knowledge that can be utilized to create solutions to issues in related domains (Van Aken, 2004). As defined by

Holmström et al., (2009), case study can be seen as part of the exploratory phase of DSR, where new theoretical insights and practical relevance are complemented.

The central of these three cycles is the design cycle, which supports a tighter cycle of research activities to construct and evaluate design works and processes. The design cycle consists of two main processes, construction, and evaluation, in which artifacts can be produced including: constructs, models, methods, and examples (Hevner et al., 2004; Peffers et al., 2008). Chapters 6 and 7 describe the design cycle of this research, including the development of the design and expert review interviews.

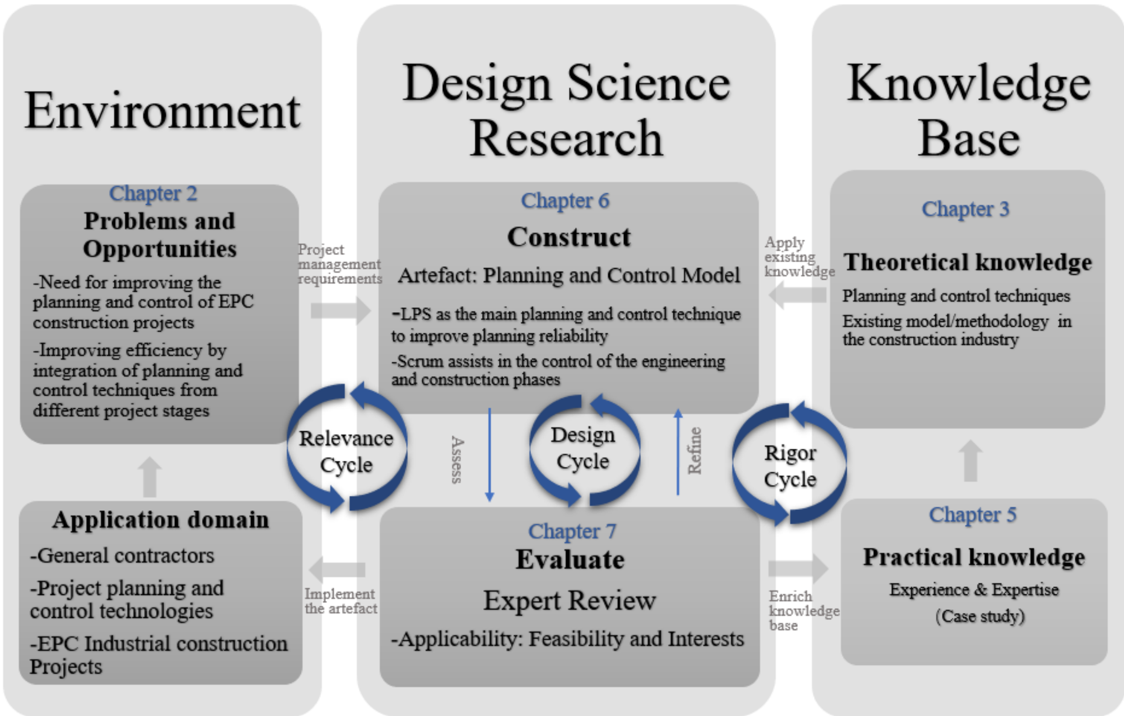


Figure 2. Design Science Research Cycles of this research (adapted from Hevner, 2007)

4.2 Research Process and methods

This research is divided into three main phases based on different research methods, each phase answering the corresponding research subquestions and corresponding to the three parts of the DSRC framework. The process of the research can be understood through Figure 3. The purpose and main activities of each phase are described in detail below.

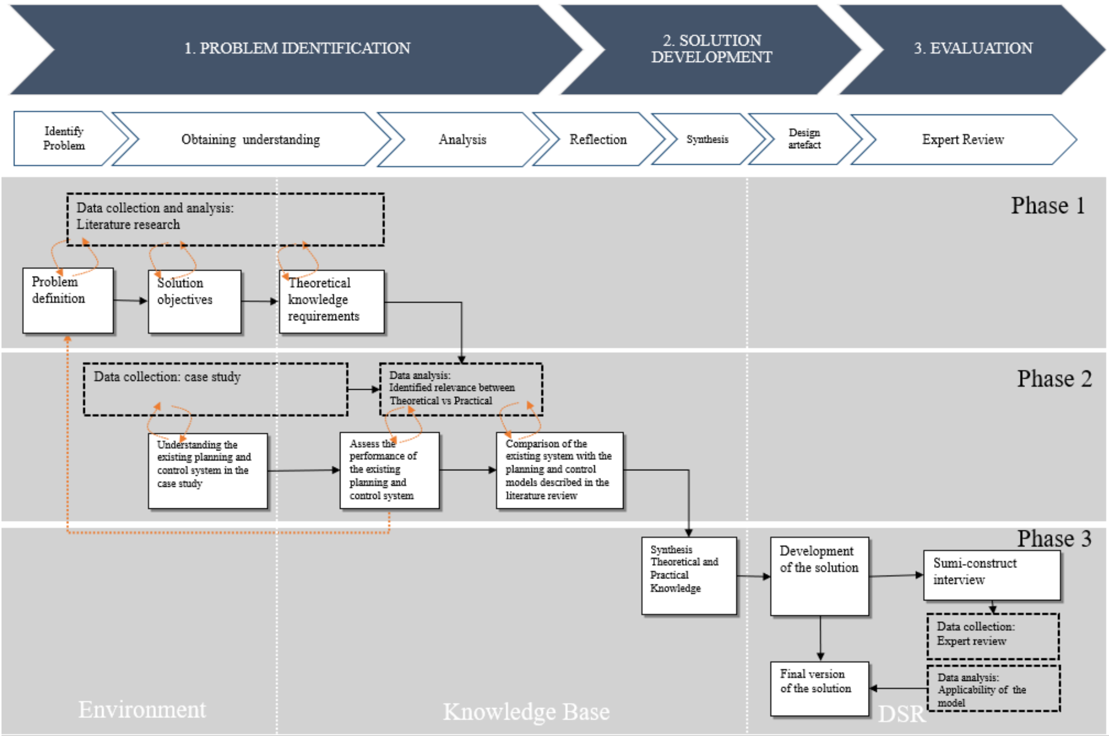


Figure 3 The research process

4.2.1 Phase 1-Literature Review

The first phase of the literature review is derived from a review of two sections. The first is to understand the problems to be solved in the specific context of EPC construction projects, whereby the first sub-research question is answered in Chapter 2: **What are the challenges of the planning and control in the complex EPC industrial construction project?**

Existing solutions are reviewed to understand how these challenges are currently addressed or proposed to be addressed from the theoretical research field, and to answer the sub question 2: **What are the requirements related to planning and control approaches to address the challenges of complexity and uncertainty associated with EPC construction projects in the existing academic literature**

4.2.2 Phase 2-Case Study

The case study phase is divided into three steps, from April 2022 to October 2022. The first step includes descriptive research of planning and control practices at the organizational level and at the project level. The second step analyzed the main consequences of the planning and control practices of the case. The third step refines the mechanisms for using these requirements in the EPC construction project environment, based on a comparison of existing methods with the requirements for effective planning and control described in the literature review. The case study phase not only provides practical experience derived from the knowledge base, but also further provides an understanding of the problem defined in Phase 1 in a real-world setting. Input is provided to both the relevance cycle and the rigor cycle. The case study used semi-structured interviews, participant and direct observation, and document analysis to collect data.

This phase answered the sub-research question 3: **How can these identified requirements be effectively implemented in an EPC construction project?**

Through this phase, the final requirements for planning and controlling EPC construction projects were refined after the case study, so it is not possible to evaluate their utility and applicability by implementing them in action research. This is a limitation of this research.

4.2.3 Phase 3-Design Science Research

In the third phase an artifact is constructed through design science research (Chapter 6) and its applicability is evaluated by experts (Chapter 7). Sub-questions 4 is answered through this phase:
How can an integrated planning and control approach be developed?

4.3 Research Scope

The scope of this research focus on the management of complexity and uncertainty in EPC projects. The target audience for this research will be general contractors who are responsible for managing these types of projects. As their interests and ambitions are different from those of other sectors, especially the public sector, and the differences of these organizations bring different challenges. The research will explore the use of both formal project planning and control technologies, such as LPS, and flexible approaches such as Scrum to manage complexity and uncertainty in these projects. The level of detail in the artifact is primarily to provide guidance for further research, as well as to provide flexibility and room for innovation in applications.

4.4 Research Strategy Summary

Table 3 summarizes the research strategy of this research by showing the three different phases and their respective research questions and data collection methods.

Table 3 Summary of the research strategy

Research Objective: Develop an integrated planning and control approach for EPC construction projects to address the complexity challenges effectively.

Main research question: How to effectively plan and control complex EPC industrial construction projects?

Research Methodology	Environment	Knowledge Base	Knowledge Base	Design Science Research
Research phase	Phase 1		Phase 2	Phase 3
Sub-questions	**SQ 1**: What are the challenges of planning and control in the complex EPC industrial construction project?	**SQ 2**: What are the requirements related to planning and control approaches to address the challenges of complexity and uncertainty associated with EPC construction projects in the existing academic literature	**SQ3**: How can these identified requirements be effectively implemented in an EPC construction project?	**SQ4**: How can an integrated planning and control approach be developed?
Research methods	Literature review		Case study	Design science research
Data collection methods			Document analysis Participant and direct observation Semi-structured interviews	Design development Semi-structured interviews
Research output	Obtain an understanding of the problem	Theoretical requirements for effective planning and control of EPC construction projects	Mechanisms and technologies that enable the effective implementation of these requirements in EPC construction projects.	An integrated planning and control approach reviewed by experts for its applicability in EPC construction projects.
Chapter	Chapter 2	Chapter 3	Chapter 5	Chapter 6 & Chapter 7

Phase 2 Case study

This phase includes the development and results of the case study. This phase begins with a description of the data sources and the focus of the data analysis for the case study (5.1), followed by analysis of the results of the case study (5.2). The results of the case study contain introduction of the existing planning and control systems (5.2.1), as well as investigated (5.2.2) and discussed performance in light of the requirements identified in the literature (5.3).

SQ4: How can these identified requirements be effectively implemented in an EPC construction project?

5. Case Study

5.1 Data Collection and analysis

5.1.1 Case select criteria

To answer the 'how' questions in a complex natural environment, a case study is one of the most appropriate methods (Yin, 2011). To select a suitable case, the following criteria are defined:

- A/E/C (Architectural, Engineering and Construction) organization serving the industrial construction sector
- The organization has implemented modern project management methods such as Lean Construction, Last Planner System, Agile, Scrum, etc. in the projects
- Modern management methods such as LPS and Scrum are combined used in all or some stages of the project
- At least two experts related to the project are available for interview

The case study was carried out at a global consulting, engineering and construction management company, serving high-tech industries around the world. The main reason for choosing this company is that it is an innovative early adopter of Lean thinking and practice and is committed to continually improving its delivery methods and is currently exploring improvements using the concepts and principles of Scrum and Agile. An industrial facility project in the construction phase was selected for empirical study at this company.

The selected project (figure 4) involves a Cell Therapy facility covers approximately 19,000m^2 consisting of ground, first, mezzanine and second stories with a plant area and glazed penthouse on the roof, which is built at the Leiden Bioscience Park (LBSP) in the Netherlands, using an EPC contract. The company selected for the case study executed the engineering, procurement, and construction stages of the project.

Figure 4 The selected project

5.1.2 Data collection methods and source of the data

The case study used multiple methods for multiple evidence collection, including document analysis, participant and direct observation, and semi-structured interviews. This allowed for data triangulation to improve the validity of the research results (Yin, 2009). Data were collected from both project level and company level. The main sources of evidence used for the case study are described in Table 4. The research and data collection activities are described in detail below.

Table 4. The data source of the case study

TYPE OF DATA SOURCE	DESCRIPTION OF DATA	DURATION	AIM
Project Document Analysis	1) Planning and control documentation (Long-term plan, project execution plan, project weekly process report, schedule, action plan) 2) LPS reports 3) Documentation for Constructability 4) Notes on discussions with construction management, sub-contractors 5) Minutes of planning meetings 6) Logistics documentation (overview of layout)	1 April-30 September 2022	The aim is to understand the practice of the project and identify opportunities for improvement.
Participant and direct observation	1) Weekly Planning meetings on-site with construction team 2) Daily meeting carried out with sub-contractors 3) Data central kick off meeting 4) Looking ahead meeting 5) Schedule integration meeting 6) Regular construction site visits 7) Observation of material storage areas 8) Observation of workflow	1 April-30 September 2022	The aim is to understand how the management team considers the needs of the construction site when planning, and to observe the decision-making process and problem-solving process
Semi-structured Interview	1) Interviewee 1: 2 semi-structured interviews with Construction manager 2) Interviewee 2: 1 semi-structured interview with Site Superintendent 3) Interviewee 2: 1 semi-structured interview with Pipe Package Owner	1) More than 2 hours 2) 1.5 hours 3) 1 hour	The purpose of the interviews is to known planning and control tasks performed by them, the role of his department in that process, performance measures adopted, and the main existing challenges of planning and control.
Company Document analysis	1) Planning and control process standard documents 2) Management tools guidelines 3) Lesson Learned document	1 April-30 June 2022	The aim is general understanding about the company context, improvement strategy, and lessons learned summarized from different projects

5.1.2.1 Document analysis

The documents are drawn from the project and the company's internal document database. These documents not only describe the standard management processes used by the organization for EPC projects (how projects are executed, planning documents, schedules), but also provide cross-sectional data and experience from different projects within the organization. The analysis of the different documents served different purposes, as detailed in Table 4.

The purpose of the analysis of the project's documentation is to obtain the relevant challenges faced during the construction stage of the project. The purpose of the review of the organization's documentation is to determine the requirements and ambitions of the organization for the planning and control systems used in the projects it undertakes. The information gathered through the document review will complement the information gathered from the literature review with practiced examples.

5.1.2.2 Participant and Observation

The data from the observations were derived from both direct and participant observation (Yin, 2011). The author was on the project site for the duration of the research. The author attended several planning and progress meetings and made occasional visits to the construction site. The author also observed the development of various plans and conducted informal exploratory interviews with various participants in the project. The interview process-maintained flexibility and asked open-ended questions to elicit their responses to the implementation process, with the aim of understanding the various processes and tasks of site management and perceptions of various issues. Typical and pressing issues in construction management planning and execution were observed, as well as the decision-making and problem-solving process and performance.

5.1.2.3 Semi-structured interviews

In qualitative and interpretative research, semi-structured interviews are frequently used to obtain data (Balushi, 2018). This method is selected for this research because it allows for the collection of diverse viewpoints from respondents and the possibility of getting insight through respondent engagement (Legard et al., 2003; Myers & Newman, 2007). The interviews were conducted with three key informants. They are Pipe Package Owner, the Site Superintendent, and the Construction Manager in the project. The purpose of the semi-structured interviews was to gain an understanding of the planning and control of the case project. This included the importance and role of planning and control in construction management, the interviewees' roles and tasks in planning and control, the development of decisions in the planning and control process, the challenges faced in the process and the interviewees' perceptions of these challenges. In addition, it provides an opportunity to gain insight into priority given to the requirements identified from the literature and the evaluation of the planning and control techniques used in the project. The semi-structured interview protocol used in the case studies is detailed in the Appendix B1.

5.2 Case study results

5.2.1 Existing Planning and control strategy

5.2.1.1 Project delivery stages and key milestone

Figure 5 shows an overview of the major project stages, as well as the key project milestones. The investigation of the author was carried out from the middle of the concrete work in the construction stage to the completion of the steel work. For the planning prior to the start of the investigation is understood through the different stages of execution planning, meeting minutes, and progress reports.

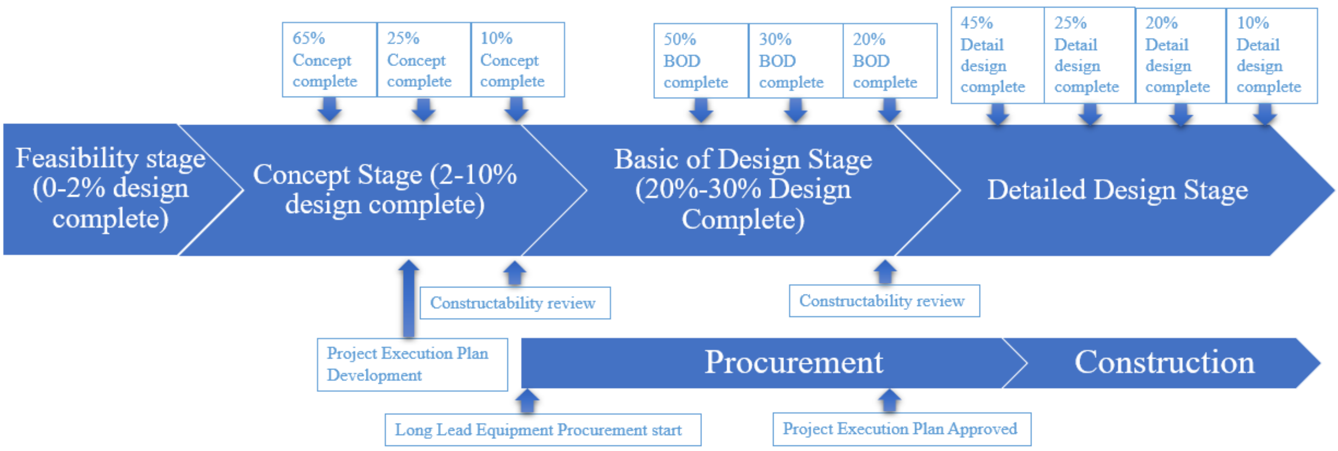


Figure 5 Project delivery stages (Source from Design Delivery Stage Map)

The scope of engineering services for this project was developed through project execution planning to ensure sufficient detail for a robust schedule and cost certainty. To optimize the project delivery model and meet the schedule, the project management team adopted a strategy of allowing as many contracting strategies as possible at each stage, within the constraints of the project schedule. The company was initially responsible for the conceptual engineering design of the project, and as part of the strategy, the company was awarded the EPC (engineering, procurement, and construction) contract during the base of design (BOD) stage. This makes the EPC contract an engineering-led one.

During the BOD stage, several early works packages were planned for tender with the aim of early award to support the permitting strategy and the start of early site construction, with the goal of meeting the early August 2021 start date while also advancing the design of elements requiring supplier input to protect the critical path of the schedule. There are more than 20 subcontractors and 40 venders in this project.

During the detailed design stage, the facility was fully 3D modeled and coordinated using real-time integrated software (e.g., BIM). In addition to the design elements to be bid by the contractor, bid packages were developed during this stage to support the BOD stage project schedule and were then bid and awarded. Any designs (e.g. modular units, cabins, etc.) that were tendered to the market during the detailed design stage were fully integrated using a BIM approach to minimize coordination risks and rework in the field that could impact the schedule.

All project participants agreed that the schedule was critical, as the project had zero float and a challenging schedule. Therefore, strategies were developed to successfully achieve project goals, minimize unforeseen events, and support the challenging schedule. Designers explored opportunities to reduce the schedule, such as modularization of project components and early procurement of long lead time equipment. Professional construction schedulers worked on an integrated EPC schedule, bringing schedule mitigation back into the schedule through measures such as pushing contractors to have earlier completion dates in their contracts than the achievable dates shown in the master schedule, allowing for double shifts and extended hours, including weekends. The constructability concept was addressed and implemented through a team effort, involving design and engineering, construction professionals, and subcontractor representatives. On-site construction was also supported by professional staff at the home office, with close coordination and communication between the site and the home office throughout the life of the project.

5.2.1.2 Existing design planning and control system of the project

The project deliverables are defined by the owner, and the control and management of design deliverables is the responsibility of the individual design discipline leads. They are responsible for understanding the committed deliverables, the number of revisions, and the deadlines for generating deliverables. The discipline lead engineer is responsible for ensuring that deliverables are completed according to the project schedule and reporting progress on deliverables at weekly design team meetings. The Project Control Engineer is responsible for monitoring the progress of deliverables and incorporating them into the Progress Measurement Report (PMR).

Early in the concept stage, a timeline was developed and used as a basis to drive the design. A key outcome of the concept design was the development of an overall Level 1 timeline for project design, construction management, with separate tasks, key milestones, and critical paths. This schedule was developed in an interactive planning session with all key design team stakeholders. Based on the interactive planning meetings, the project scheduler develops the schedule for review. Once the schedule is agreed upon, a baseline schedule will be issued, and the schedule will be monitored against the baseline. The scheduler proactively interfaces with the design lead on a weekly basis for any changes or additional deliverables and provides a weekly report to the project team at the weekly meeting, noting any issues or risks. The team also reviews the 2-week lookahead at the weekly project meeting.

The design team pre-planned all key activities and held workshops to plan resources for engineers and owner stakeholders at all locations. Meetings were held via Skype/WebEx/MS Teams to minimize disruption to the local team and to accommodate different time zones. The project management team controlled the efficiency and availability of the management team and tracked holidays to maximize stakeholder engagement. Weekly project coordination meetings were held with the design team during the BOD and detailed design stages of the project. The following key meetings and reviews were implemented to ensure effective coordination between the design disciplines:

- Internal Design Coordination meetings
- Inter-discipline Design Reviews
- Layout/Model Reviews
- Client Workshops and Design Coordination Meetings

5.2.1.3 Existing construction planning and control system

Data for the construction stage planning and control systems are obtained from construction execution plans, construction documents and reports, and field observations and participation. In addition to the construction stage objectives focused on strict implementation of a challenging schedule, safety and quality objectives also contributed to the achievement of the schedule. The project aims to achieve zero accidents (zero lost time), handover to the occupants within the allowed construction window, and successfully meet the client's requirements.

The construction execution plan for the project identified an approach that would take advantage of the continuity and flexibility inherent in the EPC (engineering, procurement, and construction) approach. The construction stage was managed using the concept of lean construction. The following figure 6 outlines the Lean Construction Tools used during the construction stage.

Lean Construction Tool	Yes / No	Scope Summary
Last Planner System	Yes	Utilised to schedule the construction works and coordinate the daily and weekly activities.
Pull Planning	Yes	Stakeholders collaborate in a single space to plan the works together as a team. The team develop how the phase build should be sequenced ensuring "hand-offs" between trades are understood.
Right First Time	Yes	This requires each subcontractor to check their own work to confirm that it has been completed to the required quality level before they confirm it has been completed on the weekly work schedule.
Collaboration	Yes	The goal of greater collaboration is to ensure that information flows accurately between all the teams involved in the project resulting in less waste and higher quality.
Go and See	Yes	This limits e-mail correspondence on a subject and encourages participants to "go and see" a problem in the field together to find and agree solutions
Choosing by Advantages	Yes	This is a methodology for sound decision making that focuses on evaluating the advantages of alternatives. This may be particularly useful in the evaluation of different modularisation offerings.

Figure 6 Overview of the LC Tools in the construction stage (source from construction execution plan

According to the figure above, LPS is a technique for planning all site activities during the construction stage. All site activities are planned and scheduled in advance, using the overall Project Schedule as a general guide. LPS in the construction stage consists of 5 conversations (refer to Appendix A1 for standard constructure) and works in conjunction with schedules, Gantt charts, and milestones.

The LPS master schedule outlines the major stages of the project and the completion milestones for the key stages. This master schedule is developed without contractor input and allows for a high level of activity to be performed and the ordering of long-term materials, but it is not typically a schedule that can be used to perform work on site. Phase planning involves the interaction of all contractors to discuss the sequence and handover of different work tasks within the construction stage in detail. This planning is commonly used in the process of Pull planning, where stakeholders collaborate in a single space and plan work together as a team. The team discusses how to sequence the stages of construction to ensure that the "handoff" between trades is understood. The project scheduler validates the master schedule based on the results of the pull planning meetings and also obtains activity resource information from the contractor through this process.

The upcoming tasks to be performed were detailed through a 6-week advance plan, and the work to be completed each week during the advance plan period was identified. The 6-week period was chosen because it is the time needed to mobilize resources to the front lines of the work. After having a 6-week look ahead, the contractor's site manager visits the site with the CMT (Construction Management Team) supervisor (field walk) and discusses the upcoming tasks at the point of execution of the work. During the site visit, any constraints that may delay the start or completion of any scheduled tasks must be identified and documented. A constraint is anything that will prevent a task from starting or finishing as scheduled, except for prerequisite work identified on the phase schedule.

Workface planning is initiated with knowledge of materials and manpower and is discussed and agreed upon with the site superintendent using Last Planner. The Site Superintendent is responsible for weekly "Last Planner" meetings to coordinate site activities. This work process will help alleviate the constraints of minimum parking space and limited available work areas and haul routes for bulk materials near the site. This will also minimize rework due to working out of sequence or assembling without complete materials available. When site activities begin, daily whiteboard stand-up meetings are led by the site supervisor to coordinate all contractors and prioritize activities that will best benefit the project in the event of a conflict of interest. Figure 7 presents the process of breaking tasks from the 6-week level to daily commitments on a weekly work plan. Learning is the final and arguably the most important level of the LPS. It is critical to improving the system as it feeds back into all the other levels and elements.

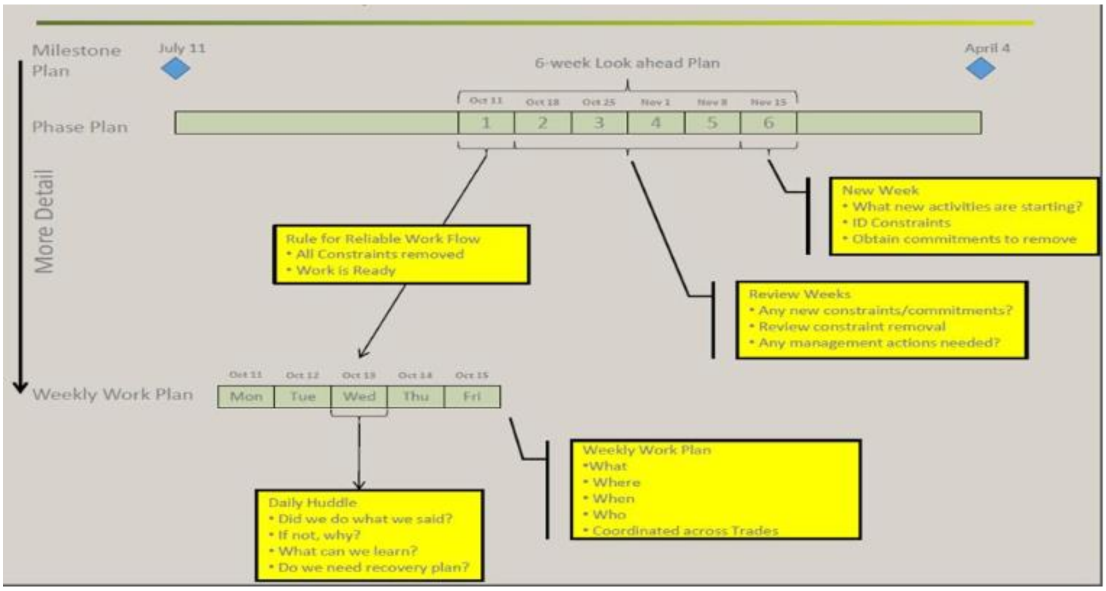


Figure 7 Weekly Schedule for LPS (source from LPS implementation guidance of the company)

The Contractor provides a weekly updated schedule to the Construction Manager and Scheduler. This is confirmed by comparison with the "actual work" for the past week in the "Weekly Work Plan" and "Percent Plan Complete (PPC) Analysis". The Scheduler updates the Master Schedule based on information from the Contractor. The construction site weekly meeting calendar includes the agreed upon LPS weekly meetings as shown in the example in Figure 8.

LPS Weekly Cycle

Mon	Tue	Wed	Thur	Fri
Daily Huddle (0830-0900, 15 - 30 Min)	*Daily Huddle* (0830-0900, 15 - 30 Min)	*Daily Huddle* (0830-0900, 15 - 30 Min)	*Daily Huddle* (0830-0900, 15 - 30 Min)	*Daily Huddle* (0830-0900, 15 - 30 Min)
	Make Ready Planning Walk (0900-1000) **Constraints Meeting** (1100-1200)	**Contractors submit WWP to DPS** (Noon, E-mail)	**Time for realignment between contractors WWPs**	**Time available for Phase/Pull Plan sessions or updates**
LPS Engineer to issue PPC Report and update scheduler on progress		**LPS Engineer collate WWPs into a single WWP**	**Weekly Coordination Meeting** (Roll out of PPC Analysis)	
Scheduler to issue updated 6 week Lookahead	**Contractors Prepare WWP**	**DPS CMT Review WWP**	**Issue next weeks agreed WWP**	

Figure 8 LPS and Schedule Alignment Weekly Cycle (source from LPS implementation guidance of the company)

5.2.1.4 Critical construction issues and associated practices

Due to schedule constraints, Construction Management Team (CMT) identified a number of challenges in the construction execution plan and adopted strategies during construction management. As the project involved a facility that contained a large number of different rooms and functions, the client required a staged turnover, requiring access to some areas before others were completed (early use). This meant that a successful turnover depended not only on the system, but also on the "room ready", and that the interior finishes (flooring, paint, ceiling, etc.) and areas of certain rooms would be as important as the completed system. Therefore, during the author's investigation, CMT worked to prioritize the steel components to release cladding activity and achieve a wind and rain tight building as soon as possible to get into the "rooms" for system turnover. To achieve this goal, CMT organized all work activities, safety and quality requirements, materials, equipment and trade resources by work packages and work areas (see Appendix B3) to develop a "room book" for construction room completion.

As a result of the global Covid-19 pandemic that has been challenging project productivity, tougher travel restrictions were introduced in mid-December 2021, when the project's concrete work began, which resulted in a traditionally international workforce that suddenly became less able and willing to travel. The government's recommendation to stay home in the event of cold and flu-like symptoms, and the need for any "close contacts" of those who test positive to also stay home for a few days, has also led to higher absenteeism rates. All of this erodes the size of the available labor pool. Out of labor uncertainty, the project decided to use elements of prefabricated facilities (such as PAR - Pre-Assembled Pipe Racks) to increase schedule certainty and to somewhat insulate the project from the negative impact of labor shortages associated with some trade disciplines. At the same time, CMT adjusted the work schedule, for the standard work week at the start of the project to 45 hours, including five 9-hour workdays. This schedule was beneficial because it provided continuity of work, minimized start, and stop times, and overtime and weekend work would be reserved for accelerating and catching up on critical milestones, critical path items, and special activities such as completing concrete pours and special deliveries and modular PAR placements before the end of the workday.

Through the author's on-site observations, the facility under construction occupied the entire site, which meant that as the concrete and steel work progressed, space for material and personnel movement became increasingly restricted. During the project, eliminating disruptions (constraints) to daily operations was a major factor in its successful execution, and the size of the facility on the plot presented significant challenges in coordinating lifting operations and the safe movement of personnel and materials on site. The logistics of the construction site and the coordination and prioritization of work are critical to the success of the project (completion of the challenging schedule on time). Therefore, according to the construction manager's interview, the goal of CMT's site management was to minimize the wasteful mix of motion and waiting, reduce idle time, and create an efficient working sequence where disciplines follow each other (producing a flow such as a production line) to complete the civil and steel scope in a timely manner, in accordance with lean construction principles. CMT identifies and removes these constraints through the implementation of “Constructability”, Lean visual management, “Construction Skyline” (a longer integrated look-ahead planning based on subcontractor breakdowns) (see Appendix B4), Scrum elements (see Appendix B2).

Constructability learning

The integration of construction expertise into the early engineering stage of capital projects is a practice known as constructability learning. Constructability is implemented on EPC projects throughout the world and when well-integrated into the Engineering and Procurement efforts leads to reduced rework and a safer more organized construction stage with lower costs.

The concept of constructability is addressed and implemented through the CMT effort involving subcontractor representatives and engineering, procurement and construction professionals from design and engineering through the construction stage. CMT accomplishes a number of tasks through the application of constructability including, but not limited to: establishing and maintaining a constructability log; facilitating discipline checklist reviews and identifying issues; providing input into the development of floor plans; providing input into PAR s transportation, placement, hoisting and rigging studies; identification and establishment of construction techniques and methods; development of comprehensive EPC schedules; input to contracting plans, procurement strategies and material management plans; input to and review of the design process; input to and review of design specifications; review of "lessons learned" from previous projects of the firm and owner, etc.

Visual management

The project's construction site has a dedicated mission control room, the **'Lean Room'**, which is a dedicated central location where relevant information is placed visually to drive the project on safety, quality, delivery and helps everyone across the project engage with the key information required. It is also used as a meeting space for multiple meetings and Daily meetings that relate to the data being processed inside Lean Room. The Lean room enables closer collaboration and a clearer flow of information, leading to faster decision making and better problem solving. This all helps the team to see, know, act and learn about the actual status, the forward view, and what is being done to improve performance now and, in the weeks, ahead. As problems are visible to all, including leadership, the Lean room helps leaders to offer support where needed.

In addition to the Lean Room, which presents visual data with key information, the project team used a variety of **visual tools** for visually conveying data and information that all can understand (figure 9), which creates a team bias for action but only where action is needed. Visual order is used in some area on site to show how the site is laid out and so leads to a tidy and safe workplace. The project holds a record of more than 200 safe construction days (no lost time injures). A central overview of information can be used not only to avoid information flooding, to support communication between different stakeholders and help manage ambiguity and uncertainty, which are typical issues faced in EPC projects.

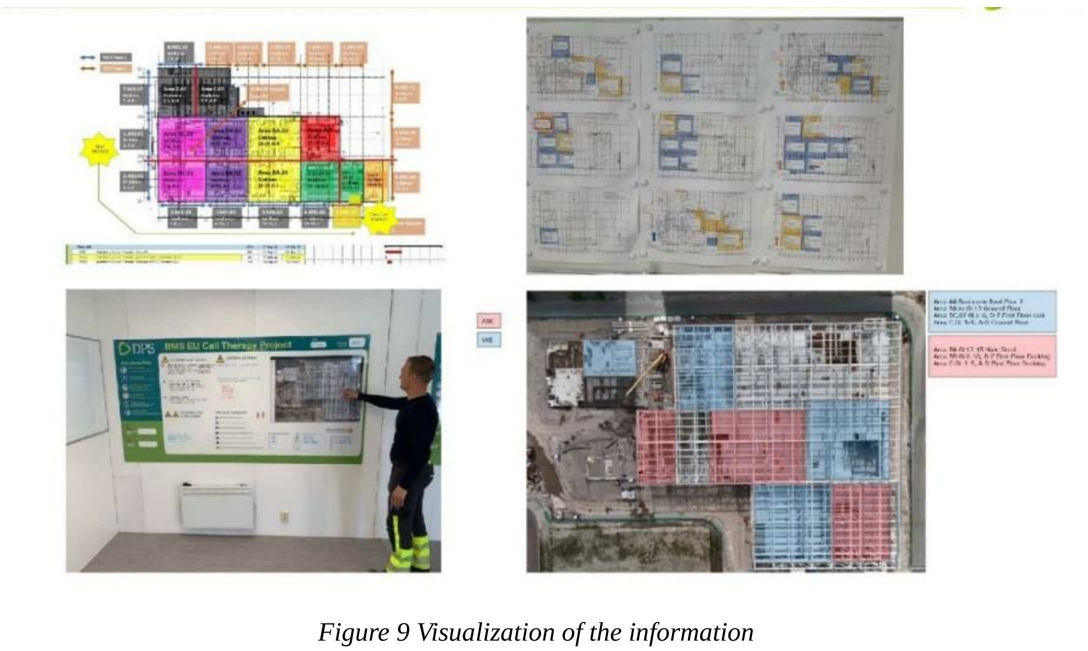


Figure 9 Visualization of the information

Construction Skyline

Managing these subcontractors was a challenge due to the project's contract procurement strategy, which involved over 20+ subcontracts for the construction of the project site. The goal of construction skyline is to consolidate lookahead plans from different time frames (e.g., 8 weeks, 6 weeks, 4 weeks, 2 weeks, and 1 week) into a single, comprehensive plan that is organized by topic or category. This plan presented in a visual format that allows all stakeholders, including the construction management team (CMT), to understand the interdependencies between different tasks, to easily identify handover constraints between different stakeholders and make informed decisions about site logistics and work sequences.

By converging the different lookahead plans in this way, it may be possible to improve the efficiency and effectiveness of project planning and control. By providing clear and sufficient information about upcoming tasks and constraints, the CMT and other stakeholders can better understand the resources and coordination required to complete the project successfully.

Scrum elements

Daily stand-up meetings (known as "whiteboard meetings" in construction execution) are led by the site superintendent to discuss the day's work and look ahead to the next day's work, focusing on logistics. The site superintendent needs to coordinate all subcontractors at the meeting and prioritize the activities that are most beneficial to the project in the event of a conflict of interest.

For changes and "surprises", CMT utilized sprint planning meetings (in the form of workshops during construction execution) to adjust their plans and priorities. For example, for the changes caused by the steel installation in Annex B2, the CMT quickly adjusted their plans in a workshop (shown in Figure 10) and defined a set of defined roles, events, and artefacts to plan and execute their work, communicating progress and difficulties among the team members through daily station meetings, and working together to accomplish the sprint goals. CMT also adopted this way of sprinting to deal with unforeseen downtime caused by the vibration of surrounding buildings due to basement construction.

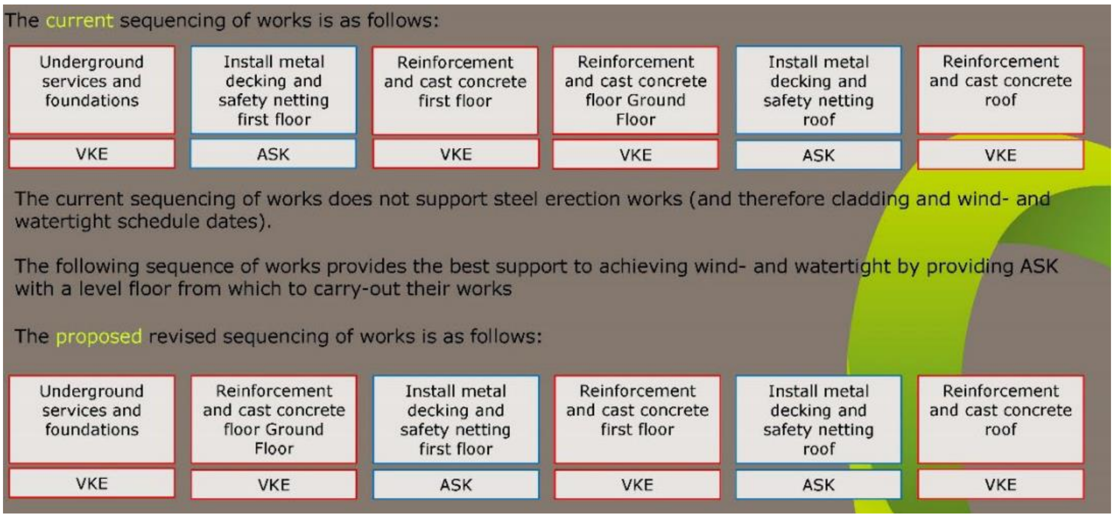


Figure 10 Revision of the working sequencing

5.2.2 Assessment of performance

The review of organizational and project documents, combined with interviews with project participants, led to an evaluation of two aspects: on the one hand, the need for effective planning and control was understood through the problems identified in the planning and control process. On the other hand, the practice of planning and control systems in the case studies is analyzed.

5.2.2.1 Planning and control system performance

A major problem with the project's planning and control system was that the project's controlling baseline was not correlated with the controlling baseline in the subcontractor's contract (as shown in Figure 11). The site manager attributed this problem to "placing unrealistic dates in the subcontractor's contract without consulting the contractor". The result was that "these dates were used by the contractor for extensions of time and commercial claims". In fact, one of the project challenges identified in the early project execution plan was "early involvement of key contractors to ensure early mobilization dates and early involvement in the design process", however, this challenge was not effectively addressed. The construction manager concluded that the project baseline schedule was developed primarily to meet the owner's requirements, and that the forecast was primarily determined by the engineer without consideration of the needs of the construction site, making the baseline schedule very unrealistic.

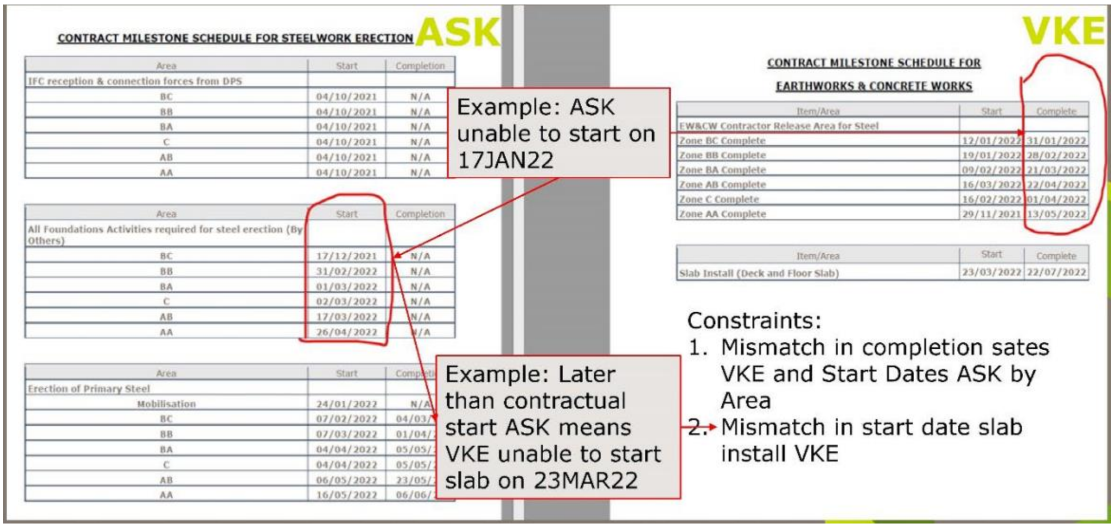
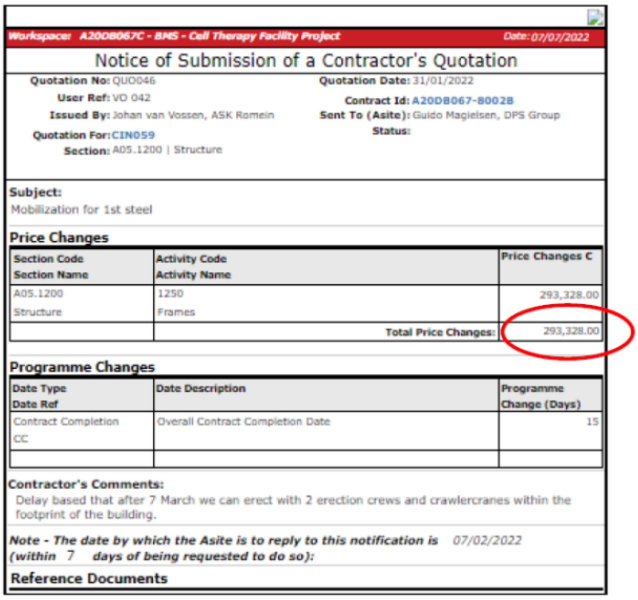


Figure 11 Misalignment of subcontractors' baselines with project baselines

Early involvement of key contractors not only ensures the validity of the baseline schedule but has the added benefit of facilitating constructability learning. While the engineers and construction manager conducted the constructability learning during the BOD stage, the site superintendent believed that the "last planner" (in this case, the subcontractor responsible for the fieldwork) was involved in the constructability learning too late." Conduct constructability learning with experienced people from the construction site and involve the contractor in these efforts at an early stage, not when the contractor arrives on site. When the contractor is ready to start work, if problems are found, it can affect the schedule and cost." As can be seen by the example in Annex B2, the lack of constructability studies with the contractor by the engineer caused it to be difficult for the sequential production and delivery specified in the steel contractor's contract to be completed in the production sequence designed by the engineer, which would have resulted in an additional €293,328 in measure costs (as shown in Figure 12) and a 2-week delay.



Workspace: A20DB067C - BMS - Cell Therapy Facility Project Date: 07/07/2022

Notice of Submission of a Contractor's Quotation

Quotation No: QUO046
User Ref: VO 042
Issued By: Johan van Vossen, ASK Romein
Quotation For: CIN059
Section: A05.1200 | Structure
Quotation Date: 31/01/2022
Contract Id: A20DB067-8002B
Sent To (Asite): Guido Magielsen, DPS Group
Status:

Subject:
Mobilization for 1st steel

Price Changes

Section Code Section Name	Activity Code Activity Name	Price Changes C
A05.1200 Structure	1250 Frames	293,328.00
	Total Price Changes:	293,328.00

Programme Changes

Date Type Date Ref	Date Description	Programme Change (Days)
Contract Completion CC	Overall Contract Completion Date	15

Contractor's Comments:
Delay based that after 7 March we can erect with 2 erection crews and crawlercranes within the footprint of the building.

Note - The date by which the Asite is to reply to this notification is 07/02/2022 *(within* 7 *days of being requested to do so):*

Reference Documents

Early warning for delayed start of steel **€293.328,-**

Figure 12 Delayed claims

The existence of the above two problems led to another problem, the lack of commitment and flexibility of the subcontractors, which posed a huge challenge to the CMT for construction control. The site manager felt that without the contractor's early involvement, there was no way to give the contractor an advance understanding of the project objectives, especially the constraints that might exist on the actual construction site. Subcontractors are not working on their own in the field; they also need to consider influences from other subcontractors. Without this early input, subcontractors would only consider what is beneficial to them when developing their schedules or planning and would lack the flexibility for changes once they start working, which come from the general contractor in order to coordinate different subcontractors working together. In order to avoid any wasted time, usually the work package owner will ask the contractor to deal with the problem immediately on site if he finds it at the construction site. However, the package owner stated that the steel contractor was quite "strict" about the junction deliverables from the concrete contractor and was unwilling to make any concessions to adapt to any "defects" from other contractors that did not affect the quality of their work. The construction manager and site superintendent indicated that increased flexibility on the part of the subcontractor would not result in excessive focus on claims but rather on working together to achieve the project goals.

For all of these problems, the Construction Manager believes that effective solutions can only be achieved through a truly collaborative, integrated model, from the proposal stage through conceptual, basic and detailed engineering, procurement and implementation throughout the construction stage. Without true integration across all stages, waste will not be identified in the early stages of the project and negative flows will be generated that will impact schedule and commercial activity. Hours reserved for early involvement of subcontractors, which, while requiring a limited investment at the beginning, will be earned back during the construction stage, thus adding added value for the client.

5.2.2.2 Applicability of planning and control practices

According to interviewees, design deliverables were delivered slowly on projects, or there were multiple deviations in quality that did not allow enough time for review and correction. Although the detailed design schedule was integrated with construction and procurement into a controlled schedule, according to the site supervisor, the construction stage was impacted by the inability of the engineering department to effectively control the design schedule and quality. Based on the engineering design delivery strategy in 5.2.1.1, a more detailed structured framework was used for design development from concept to construction. Since the company is design-led, the strategy is appropriate for the generation and delivery of design deliverables when its scope of services is limited to projects with engineering design. However, as the scope of services expanded (EPC contracts were awarded), the design tasks that were originally required of engineers to complete only the owner's requirements began to become complex. The construction manager stated that the engineers were "lazy" and only wanted to complete their design work, not the project.

The company, concerned with the lack of effective planning and control of the design process, implemented a combination of LPS and elements of the Agile Management and Scrum frameworks (See Appendix B2) in some projects for design management to minimize the impact of complexity and uncertainty. The company's case study documentation stated that there was a significant improvement in its delivery process. While the design work does not have the hard logic of architectural work, it is still done in a network of commitment between experts. This network can be designed and managed so that the work that should be done can be done and will be done. Increased collaboration ensures that the information needed to complete design tasks is adequate and reduces inconsistencies in deliverables and design duplication of effort. While the use of these frameworks was intended to minimize the impact of complexity and uncertainty, it appears that the engineers and engineering manager of the project were not trained in their use and were therefore unable to utilize them. This lack of understanding and training may have limited the effectiveness of these frameworks in improving the design process. Therefore, the investigation of the use of LPS and Scrum in the design stage is a limitation of this report.

Based on construction site observations and participant feedback, all 5 planning levels of LPS were used, weekly meetings were held on time and participation was high, daily meetings of Scrum were held on time. The tools from Lean Construction are also used for project management.

According to feedback from construction managers and site supervisors, although different levels of LPS planning are used, the functionality of LPS is not fully realized.

For example, the project's baseline practice sheets and standard sequence of activities were not completed in a truly collaborative manner, leading to changes later in the process due to coordination of different stakeholders. Such changes they thought could be identified and dealt with early on. As a result, the baseline schedule and standard sequence of activities were no longer effective in guiding the construction stage, and based on this lesson learned, they used the "construction skyline" to identify early on the constraints between the different stakeholders that impacted the construction site and used pulling planning to adjust the planning and develop an optimal sequence. The remaining subcontractors had not started work by the time the author concluded the research, so validation of the utility of this tool is a limitation of this research. However, feedback from interviews with package owners who managed subcontractors and from related workshops learned that they believed that this approach gave them transparent information about the work and junctions of different subcontractors and helped them to identify and analyze potential constraints.

The company’s documentation shows that a lack of effective planning and control often leads to inefficient management of constraints and an inability to create workable workflows, resulting in waste and delays. It is found that to enable smooth workflow it is critical to identify and remove constraints as early possible prior to the task execution date. Identifying constraints as late as seven days prior to being needed doesn’t allow adequate time for resolution. Figure 13 (Constraints Health) shows too many constraints being raised within seven days, resulting in late resolution of 49% of the constraints (Constraints Removal Health). Ideally, constraints should be identified at least three to four weeks in advance.

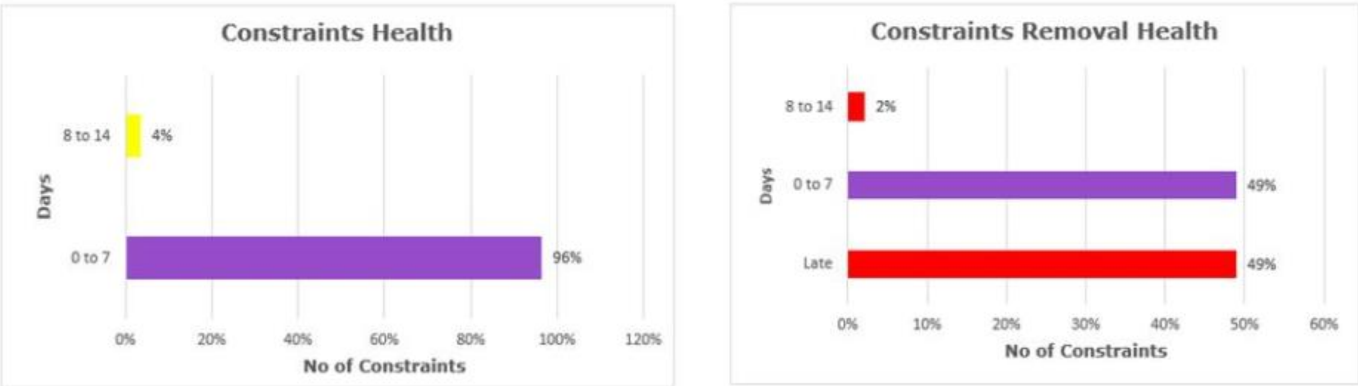


Figure 13 Constraint Removal Visualization

The company's experience with LPS and project implementation has highlighted that the constraint management process is the biggest contributor to effective LPS implementation. However, effective constraint management requires not only the early identification of constraints, but also the removal of constraints as early as possible. Traditionally, identified constraints are recorded on an excel sheet and emailed to the person identified as best placed to address the issue. This process is slow and tedious as someone must continually chase the individual to resolve their assigned constraint and there is a lot of back and forth seeking clarification both in terms of requests and responses. The average time to resolve each constraint in 2018/19 was 17.5 days. In addition, seven days may be too long for the design process to wait for a constraint to be removed. The organization concluded that it is important to obtain commitment from individuals to remove constraints.

The Scrum element can be considered applicable to the handling of changes and constraints during the construction stage. According to the company's survey, the average time to resolve each constraint was 17.5 days in 2018/19. By applying Scrum and Kanban to the constraints process, the duration of each constraint is reduced to 3.2 days by mid-2020. Figure 14 illustrates the resulting improvements. The company highlighted the constraint management process as the biggest contributor to effective LPS implementation, but LPS fell short in the handling of constraints.

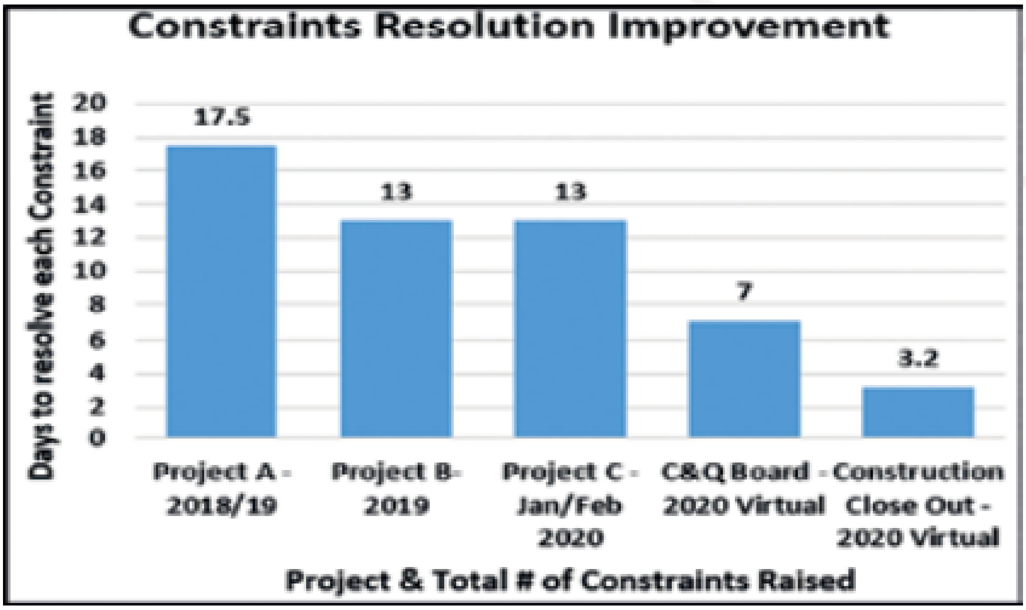


Figure 14 Construction resolution improvement

It is clear from the observation of the daily meetings of the project on the handling of constraints that Scrum elements can facilitate the efficiency of the handling of constraints. Construction managers view the process of handling constraints as like breaking the project into smaller pieces (called "sprints") and treating each sprint as a mini project with its own goals, deliverables, and deadlines. This will help manage projects more effectively and respond more quickly to changes in the project environment. In addition, the decision-making process for such small projects is more efficient due to the more focused size of the sprint team. In addition, the decision-making process for such mini projects is more efficient due to the more centralized sprint team size. Based on feedback from the package owner, this process requires the superintendent (equivalent to a Scrum master) to coordinate feedback well between the different members, regularly review and adjust their plans based on this feedback and the changing project conditions. The site superintendent argued that the general contractor was able to adapt quickly to changes through sprint planning, but that it was a challenge to gain flexibility from the subcontractors. In his opinion, creating a team with subcontractors that share common goals at each sprint can be effective in meeting this challenge. Another challenge is that there is always a "cost" to adapting to change. But adopting the "best" adaptation strategy can reduce this "cost. For example, in dealing with changes in steel installation, positive "adaptation" (changing methods) reduces wasted time and reduces the cost of temporary facilities and extended time than negative "adaptation" (waiting and using the old methods).

5.3 Comparison case study findings with Literature findings

In this section, a set of requirements identified from the literature is compared with the actual practices used in a given project by evaluating how well the requirements of the theory are reflected in practice and whether the techniques used in the project are effective in meeting those requirements. The applicability of planning and control techniques in practice is then discussed. This can help to prepare for an effective planning and control approach that is tailored to the specific needs of the project.

5.3.1 Multi-level planning and control

Multi-level planning and control is a hierarchical way of decision-making and problem solving in complex systems. It is also a mechanism for coping with uncertainty and change, with detailed short-term plans developed only when reliable and up-to-date information is available. The company's division of the engineering stage into smaller, more manageable parts for the development of deliverables can also be seen as a multi-level strategy. In addition to using the different levels of the LPS for the construction stage, the lookahead plans were further optimized separately into different categories since there were multiple sources of uncertainty. All these mechanisms help to identify constraints in advance using effective information to deal with the complexity and uncertainty arising from multiple activities and stakeholders. However, long-term planning developed during the engineering stage is unreliable due to the lack of communication with the project stage. Therefore, multi-level planning is only effective when it is properly integrated and truly collaborative.

LPS plays a crucial role in realizing this need for multi-level planning and control of projects, as it is a multi-level planning and control system with clear links between the levels. It is a mechanism that shields production and makes it very efficient, which is arguably the most important function of the LPS (Howell, 2020).

5.3.2 Collaborative planning

Collaborative planning is a process in which multiple people or organizations work together to develop a plan or strategy. It involves open communication, shared decision making, and a focus on reaching a mutually beneficial outcome. In the investigation, collaborating with the owner during the engineering stage helped to better define the project scope to meet the owner's needs. Constructability studies during the engineering stage are collaborative efforts between members of a general contracting project. By considering constructability during the engineering stage, engineers can design solutions that are easier to build, use fewer resources, and result in fewer delays or disruptions during construction. However, constructability studies should involve multiple stakeholders, including engineers, contractors, and subcontractors. This process for the project did not pull subcontractors into the planning process, their voices were not heard, and a plan that does not meet the needs and goals of all parties involved ultimately creates challenges for the general contractor's flexibility. Therefore, it is important to involve all stakeholders, including subcontractors, in the collaborative planning and constructability learning process in order to ensure that the needs and goals of all parties are considered and addressed. By involving subcontractors in the planning process, it is possible to incorporate their expertise and experience into the design and construction of the project. This can help to improve the efficiency and reliability of the project and ensure that all parties are committed to the success of the project.

In addition to involving subcontractors in the planning process, it is also important to ensure that open communication and shared decision making are a key part of the collaborative planning process. This can help to ensure that all stakeholders are able to contribute their ideas and concerns, and that any potential issues or challenges are identified and addressed in a timely manner. Both LPS and Scrum have served well in facilitating collaborative planning. Both the integrated lookahead planning meetings and pull planning meetings in LPS have increased participation from different stakeholders, and Scrum's daily meetings have had high participation levels. These integrated planning meetings led to better information, and the short meetings increased decision making participation and problem solving. Collaborative planning makes planning less centralized and engineers and subcontractors more committed to task completion.

5.3.3 Effective managing constraints

One effective mechanism for managing uncertainty in construction projects is to utilize lookahead planning to identify potential constraints in advance and optimize task prioritization to minimize waste. This can be especially important in projects, which often involve many different disciplines and stakeholders and can take a long time to complete. In the case study described, multiple levels of lookahead planning were used to address different sources of constraints. In the engineering stage, two levels of lookahead planning were used to identify and analyze external factors (such as those coming from the client) and internal constraints within the project team (such as those between different disciplines). In the construction stage, lookahead planning was used to confirm the site constructability of subcontractors of different disciplines.

In addition to comprehensive identification of constraints, it is also important to have a process in place for efficiently removing constraints. The use of Sprint planning and daily stand-up meetings (also known as daily scrums) can be effective in this regard. These meetings provide a forum for team members to discuss their progress, challenges, and plans, and can help facilitate collaboration and communication among team members. By holding daily stand-up meetings on a consistent basis, team members can stay informed about what is happening on the project and can more easily collaborate to address any issues that may arise. Overall, the combination of lookahead planning and Scrum seems to be an effective approach for managing constraints and addressing uncertainty in construction projects.

5.3.4 Providing adaptation

Providing adaptability to the project planning and control process is crucial for achieving flexibility and successfully managing uncertainty in construction projects. The CMT in the project responds to change through Sprint planning, making the best decisions for handling change, and on the other hand, adjusting the construction sequence guided by the project goals to facilitate the achievement of the project goals when the execution plan is found to be no longer effective. Look-ahead planning and pull planning can help identify potential issues and risks in advance and allow the project team to adapt and find the best solutions to meet changing needs and circumstances. Scrum also emphasizes rapid response to changing delivery conditions and efficient removal of constraints, which can help teams adapt to unexpected challenges and changes in a timely manner. Together, these approaches can provide the mechanism for effectively managing change and adjusting methods that are no longer effective.

However, a key challenge in the generation and implementation of alternative solutions using flexibility strategies comes from the commitment of the task performers (subcontractors/engineers). Project managers require the use of collaborative arrangements to planning and executing alternative solutions, yet contractors often do not fully understand what this means and how they should behave in such a project (Davis and Love, 2010). Task implementers try to protect their own interests rather than find the best solution. This can lead to difficulties in achieving consensus and effectively implementing alternative solutions. It is important for project participants to work on developing a collaborative attitude and a willingness to be flexible in order to address these challenges and successfully manage uncertainty in construction projects.

5.3.5 Providing opportunities for learning

Effective learning and continuous improvement are crucial for managing complexity and change in construction projects. Exploratory learning, which involves searching for and creating new knowledge, can be enhanced through strong collaboration and regular planning meetings. Reflective learning, which involves analyzing past failures and taking countermeasures to prevent them from happening again, is also important for maintaining system reliability and continuous improvement.

Maintaining continuous improvement requires updating relevant levels of planning and developing improvement plans based on the learning that has taken place. In the case study mentioned, it was observed that the project team used visualizations and look-ahead planning to stay informed and adapt to changes in a timely manner. The daily meeting in Scrum is also a form of reflective learning that helps teams review progress and identify any issues or obstacles that need to be addressed. Overall, a focus on continuous learning and improvement can help construction teams adapt to changing circumstances and achieve the project goals.

5.3.6 Increase transparency

Transparency in the planning and control process is crucial for managing complexity and uncertainty in EPC projects. By making information and decision-making processes more transparent, teams can better understand each other's roles and responsibilities, leading to clearer and more effective communication. This can help improve efficiency by enabling teams to make more informed decisions and avoid unnecessary delays or rework. Transparency also enhances accountability, making it easier for team members to be held accountable for their actions and performance.

LPS and daily stand-up meetings are effective mechanisms for increasing transparency of information and facilitating better communication among team members. A clear and comprehensive understanding of the project can also help the team identify and address potential risks in a timely manner, reducing the likelihood of unexpected delays or cost overruns. The combination of lookahead planning and visualization tools provides the team with the means to effectively identify constraints and potential changes.

In the project, the organization used tools such as visualization tools, project management software, and regular meetings to establish clear communication channels and encourage open and honest dialogue among team members. This helped increase transparency on the EPC project and improve the overall management of the project.

5.4 Case study conclusion

The identified requirements for effective planning and control in EPC construction projects can be effectively implemented through the adoption of a flexible approach that focuses on quickly identifying and addressing foreseeable uncertainties and collaborating with all relevant parties from the early stages of the project. This approach involves the use of tools such as LPS and Scrum, as well as the promotion of collaborative communication and exploratory learning. The case study presented in this research demonstrates the successful application of this approach in the construction stage, improving understanding of the benefits of using Scrum, facilitating effective communication, and increasing the effectiveness of guidance provided by the Scrum master. However, it is important to note that the successful implementation of these requirements in an EPC construction project requires a combination of flexibility, collaboration, and the use of appropriate tools and techniques. In the next chapter, solution will be designed through the application of design science research method, incorporating the theoretical knowledge presented in Chapter 3 and the practical knowledge gathered through the case study.

Phase 3 Design Science Research

This phase will begin to develop the solution by combining theoretical knowledge from the literature and practical knowledge from the case study, review the solution through experts in the industry, and finally refine the solution and make recommendations for practice and further development.

Chapter 6 describes the development and final design of the solution. Chapter 7 illustrates the results of the expert review. Chapter 8 discusses the practical and theoretical relevance of this research, as well as the limits of the research.

6. Solution Development

First, the scope of model use and audience is defined in section 6.1. Based on the findings of chapter 4 and section 5.1, a series of requirements for the design of the planning and control model are refined, and the applicable elements of LPS and Scrum are associated by specifying the application mechanism in section 6.2.1. The synergy of the requirements is discussed in Section 6.2.2. The final version of the solution is presented in section 6.3.

6.1 Context of the solution

The target audience for the artifacts designed for this research is the EPC project general contractor, and several assumptions are made regarding the target audience: the project general contractor is an engineering driven organization which has the ability to be responsible for all specialized engineering design services as well as all construction services required to build the project, and general contractors are open to Lean and Agile concepts and constantly have the desire to make things better, such as finding the best solutions to the uncertainty challenges faced by complex projects. The artifacts designed in this research are intended to provide guidance on the implementation of a more flexible approach to planning and control in EPC construction projects, specifically in addressing uncertainties and promoting collaboration. The artifacts are intended to be used by project managers and other relevant stakeholders in the planning and control process, such as engineering and construction managers, to improve the efficiency and effectiveness of their projects.

6.2 Synthesis

6.2.1 Requirements and associated mechanisms for planning and controlling EPC industrial construction projects

Based on the analysis of the case study, the set of requirements for effective planning and control was redefined considering the project context and the target audience of the EPC industrial project. Table 5 lists the set of requirements and the mechanisms to be considered when implementing each of them.

Table 5 Requirements and associated mechanisms for planning and controlling EPC industrial construction projects

Requirements		Mechanisms that can be used to associate with each requirement in the practice of EPC industrial construction projects	Source of the requirements	Techniques and the elements
R1	Muti-level planning and control	• A logical network conforming to the available time for project delivery • A logical network that connects milestones and includes actions required in later phases that must occur in earlier phases, such as long-lead projects • Identify all constraints based on available information before the task begins • Once all available resources are identified, a more detailed plan needs to be completed	Literature review	LPS: • Project execution planning • Master planning • Lookahead planning • Weekly planning
		• Integrate and update different levels of planning and control by create a structured weekly meeting cycle • The engineering design process is result (value) oriented and is planned in accordance with disciplines reduced design batches.	Case study	• LPS and Schedule Alignment Weekly Cycle • Daily meeting Scrum: • Product backlog • Sprint Backlog
R2	Collaboration planning	• Involve representatives of all project stakeholders in setting in-use net benefit targets (what is wanted and constraints on acceptable delivery) • Involve those with direct knowledge of and responsibility for the work in developing the work plan develop the project delivery plan • Collaboration needs to focus on enhancing cooperation in joint exploratory learning and adaptation so that key stakeholders can leverage their complementary knowledge and work together to develop new solutions that meet their diverse goals • Stakeholders work as a team to develop a sequence of a phase to build and ensure that the "hand off" between disciplines is understood.	Literature review	Pull planning: • Pull planning project execution plan with stakeholders from different stages of EPC • Pull planning the sequence of a stage • Pull planning to identify the constraints
		• Implementing collaboration constructability learning in the engineering stage as early as possible, and continue through the project execution	Case study	• Pull planning project execution plan with stakeholders from different stages of EPC • Pull planning engineering/procurement/construction execution plan
R3	Effective managing constrains	• All potential constraints need to be effectively identified in advance at all project stages as well as at the interfaces • Make sure that all constraints affecting the task are removed before the task begins officially	Literature review	LPS • Lookahead planning • Action plan Scrum • Sprint planning
		• Identify and remove constraints by category based on project complexity and needs • Constraints need to be addressed quickly to avoid schedule delays and improve the productivity of complex construction projects	Case study	• Different levels of Lookahead planning • Sprint planning • Sprint backlog, Daily scrum

Requirements		Mechanisms that can be used to associate with each requirement in the practice of EPC industrial construction projects	Source of the requirements	Techniques and the elements
R4	Adaptable	• Find and implement new alternative plans and procedures in the face of unforeseen problems and environmental changes that inevitably arise • Rapid adaptation processes to avoid serious time overruns when faced with significant unforeseen situations • Identify inefficiencies in original planning and production methods and quickly initiate adaptations	Literature review	LPS • LPS and Schedule Alignment Weekly Cycle Scrum • Sprint planning • Sprint backlog • Daily scrum
		• Define and change schedules for different tasks to keep the baseline when changes are encountered	Case study	LPS • Milestone Pull planning Scrum • Sprint planning
R5	Provide opportunities for learning	• Understand the goals and objectives of the stakeholders on which project success depends through exploratory learning • Project participants make consistent decisions more quickly through joint exploratory learning to develop new alternatives • Regular reflective learning to define the problem to its root level to eliminate/reduce the chance of recurrence	Literature review	Pull planning LPS • Lessons learned and action plans for prevention Scrum • Sprint planning • Sprint review
		• Regularly review and update relevant levels of planning and develop improvement plans based on learning	Case study	LPS and Schedule Alignment Weekly Cycle Sprint planning
R6	Increase transparency	• Use systematic visual management tools to increase information transparency • Hold regular meetings or check-ins with all stakeholders can help to keep everyone informed about the project's progress and any issues that may arise. • Keeping thorough and up-to-date documentation, such as project plans, schedules, and budget reports, can help to provide a clear overview of the project and its status.	Literature review Case study	Visual tools LPS • Structure meeting cycle • Lookahead planning Pull planning Scrum • Daily meetings

6.2.2 Synergy between requirements

Figure 15 systematically demonstrates the synergy of requirements. Managing uncertainty is viewed in this research as a focus for managing an EPC industrial construction project, and it plays a crucial role in the development of effective planning and control system. In this research, a system for managing uncertainty is one that combines control and flexibility, requiring control over predictable uncertainties (constraints) and rapid adaptation to unpredictable changes.

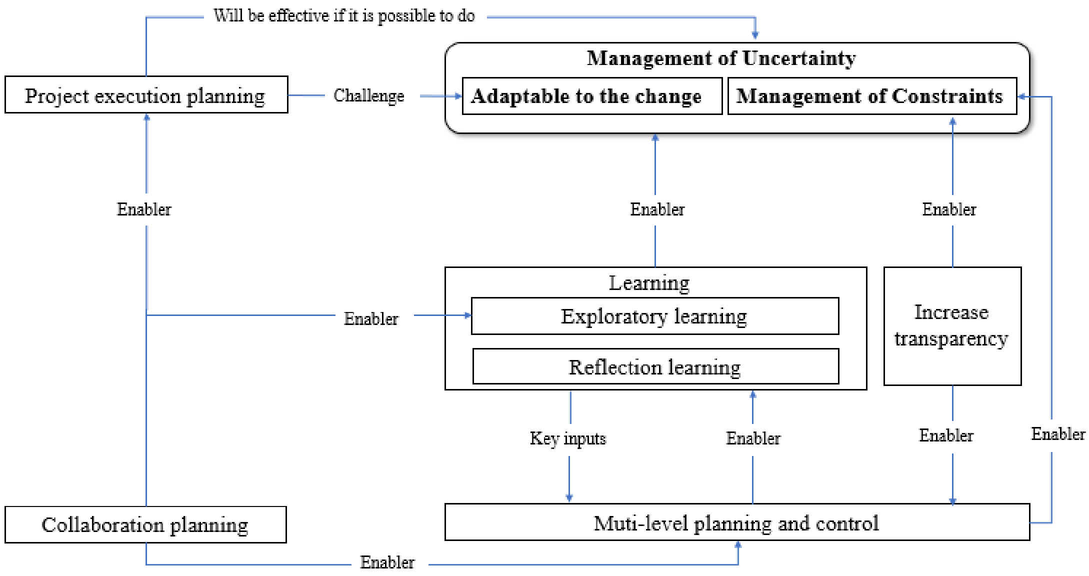


Figure 15 Synergy between requirements

The starting point for effective planning and control of EPC projects is the identification and management of uncertainties. By proactively seeking new information and reflecting on past experiences, project participants can be more flexible and better able to adapt to changes or unexpected events. In addition, using different levels of planning and control, from strategic to operational, can help identify and manage uncertainties more effectively and increase the reliability of the planning process.

Involving all stakeholders in the planning process, including engineering, procurement, and construction, can help identify and resolve potential problems and constraints early on and increase the reliability of project execution plans. Collaboration can also promote trust and improve communication among team members, leading to better decision making and problem solving in a multi-tiered planning and control process. A strict delivery planning is a major challenge for project flexibility.

A multi-layered planning and control system, combined with exploratory and reflective learning, can introduce a degree of flexibility to the planning and control process, allowing the project to adapt to changes or unexpected events. Exploratory and reflective learning can provide opportunities for project participants to learn from past experiences and adapt to new situations, improving the accuracy of expected project delivery times and increasing overall efficiency.

Finally, increased transparency in the planning and control process is critical to effective planning and control. By making project information visible to all stakeholders, it can facilitate uncertainty identification and better decision making and problem solving, as well as build trust and cooperation between the project team and other stakeholders.

In summary, these requirements for effective planning and control in EPC projects are interconnected and work together to improve efficiency, adaptability, and success, ultimately leading to more reliable project time performance.

6.3 Elaboration of the Proposed Approach

Based on the combination of theoretical and practical knowledge (Table 5), this section will present an enhanced technique to improve the planning and control process of EPC construction projects by combining the concepts of LPS and Scrum. Figure 16 illustrates a schematic diagram of the combination of LPS and Scrum techniques. Detailed descriptions in association with the relevant requirements are as follows.

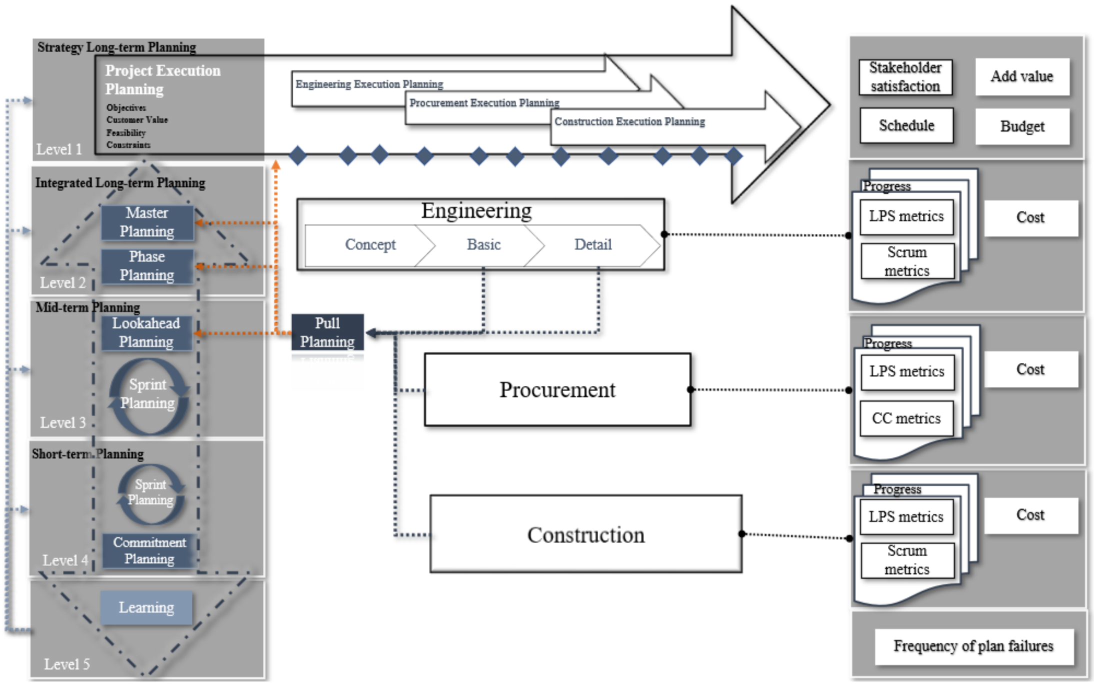


Figure 16. Combination of LPS and Scrum in EPC construction projects

Use LPS techniques such as pull planning and phase planning to create a comprehensive long-term plan for the project, and break the project down into smaller, more manageable parts. Use Scrum techniques such as daily stand-up meetings and product backlogs to facilitate frequent communication and collaboration among team members and prioritize tasks based on importance and value.

Strategic long-term planning

Implement strategic long-term planning using pull planning: This process involves presenting project requirements to the "last planner" and initiating a cycle of reliable commitment by specifying what is wanted and the conditions to be met. A project execution plan can be developed based on contract completion dates, allowable budgets, and identified risks and opportunities. This plan can be refined and improved as the engineering stage progresses, especially by continually completing constructability learning.

Integrated mid-term planning

This process integrates all stages of EPC construction project planning through pull planning to create a unified master plan to guide project delivery. Phase planning can then be used to divide the project into smaller, more manageable sections or stages and develop a plan for each stage. This allows the project team to focus on one stage at a time and better coordinate and control the various elements of the project.

Mid-term planning

Mid-term planning involves identifying tasks and activities to be completed, allocating resources and materials, and setting deadlines to ensure that the project is completed on time and within budget. This can be done using LPS techniques such as integrated mid-term planning meetings and pull plans, which involve collaborative and decentralized decision making to improve planning reliability. Forward-looking pull-based scheduling systems can be used to optimize workflow and minimize waste by identifying and addressing constraints before they become critical. Other techniques that can be used for mid-term planning include product backlogs, which prioritize tasks based on importance and value, and daily stand-up meetings to identify and resolve constraints and facilitate frequent communication and collaboration among team members.

Medium-term planning facilitates not only the management of constraints, but also provides adaptability for the project. Use sprint planning and sprint reviews to continuously review and adjust the project plan. In Scrum, iterative development involves breaking the project into smaller chunks called sprints, and regularly reviewing and adjusting the project plan based on feedback and progress. During sprint reviews, team members can identify areas for improvement and implement changes to optimize future project plans and control processes to ensure they stay on track.

Short-term planning

Short-term planning involves planning and controlling the work to be done in the short term, usually within the next week or two. both the Last Planner System (LPS) and Scrum can be used to implement short-term planning in an EPC project. In LPS, weekly work planning meetings are used to plan and control the work to be done in the short term. In these meetings, team members collaborate to identify tasks and activities to be completed, allocate resources and materials, and set deadlines to ensure that the project is completed on time and within budget. Scrum sprints can help not only to quickly remove constraints to facilitate short-term planning, but also to quickly deal with unforeseen changes. Constraints and changes can be broken down into different short-term sprints using iterative development in Scrum, and these sprints can be handled through sprint planning and daily station meetings to review and adjust the project plan to provide adaptability and agility.

Visual management

During the planning process, use visualization tools, such as task boards or Kanban boards, to visualize what needs to be done, what is being done, and what has been done. This helps increase transparency and makes it easy for everyone to see what work is being done and the status of each task.

Continue improvement

Regularly review and update the project plan to ensure that it accurately reflects the current state of the project and any changes that have been made. Regularly monitoring and reviewing progress is essential for identifying and addressing any issues that may arise. Use metrics analysis to track progress and identify areas for improvement.

By following this enhanced approach, EPC construction projects can handle the uncertainty and complexity of construction projects in a formal and flexible manner while meeting the requirements of multi-level planning and control, collaborative planning, effective management of constraints, adaptability, learning opportunities, and increased transparency. This can improve the planning and control process and provide greater value to stakeholders.

7. Expert Review

This chapter presents an expert review of the proposed methodology. 7.1 details the approach to conducting the review, the selection of experts, and the protocol for the review. 7.2 presents the results of the expert review.

7.1 Data collection

7.1.1 Review approach

The expert review is used to assess the adaptability and potential practical issues of the approach. The experts will also make recommendations of solutions to potential problems. The approach is constructed using different planning and control technology elements within the context of the redefined design requirements. As there are different planning and control techniques and different practices, it is not possible to review all the technical elements that could potentially make up the model, and as the model is not able to be applied in the field during the research to assess its utility.

7.1.2 Expert selection

The expert review uses the same method of collecting data as the semi-structured interviews. As most of the elements for constructing the model come from modern management techniques the LC and APM, one of the obstacles to evaluation is the selection of participants and their knowledge of EPC project planning and control techniques, especially LPS and Scrum. The experts were mainly from the case company's internal sources; one expert changed his employer during the research process, so his latest company is shown in the expert list. If relevant participations are not feasible, alternatives will be considered. Table 6 shows the respondents selected, their role and years of experience in that role. A total of four experts are selected, all of whom have over ten years of experience in industrial project management, are familiar with various planning and control techniques and have their own insights into the practices of the EPC projects.

Table 6. Experts in the Expert Review

Organization	Code	Experts	Work experience	Date interview
Company D	EX1	Project Manager	15+	18-11-2022
	EX2	Engineering Manager	20+	21-11-2022
	EX3	Project Control Manager	10+	23-11-2022
Company S	EX4	Construction Manager	20+	25-11-2022

7.1.3 Evaluation Protocol

The evaluation protocol is designed to guide the author throughout the discussion with the experts. The composition and detailed description of the expert review guidance is detailed in Appendix C. The expert review is conducted in three parts. The experts first carry out a qualitative analysis of the design requirements, which form the basis for the construction of the approach and therefore need to know whether they are accurate and relevant. Secondly, the technical elements used in the approach are evaluated to see if they meet the requirements. This is a comprehensive understanding of the structural integrity and soundness (strengths and weaknesses) of the approach. Finally, barriers to the use of the approach and solutions are discussed to understand the applicability of the approach in practice and areas for improvement.

7.2 Expert Review Results

The expert evaluation process is discussed according to two main themes.

- The requirements for constructing the approach.
- The applicability oof the combination of LPS and Scrum techniques.

The following subsections discuss the results of these two themes in detail.

7.2.1 Review of the requirements

7.2.1.1 Applicability of the requirements in planning and control of EPC industrial construction projects

It appears that the experts involved in the planning and control process of EPC industrial building projects agree that coping with uncertainty is the most important role of planning and control. They also recognize the importance of flexibility and adaptability in the planning and control process. However, there seems to be some disagreement among the experts about the relative importance of other requirements, such as multi-level planning and control and reflective learning.

Expert 3, who is an engineering manager, believes that a multi-level planning and control process is important for identifying and resolving uncertainties. In contrast, expert 4, who is the construction manager, believes that this requirement is less important due to the different sources of uncertainty that they encounter as a general contractor working with external subcontractors.

Expert 4 also expressed skepticism about the value of reflective learning, stating that lessons learned from different sources may not be universally applicable and may be prone to bias. However, expert 1, who is the project manager, values the richness of information and knowledge gained through collaboration and sees it as important for making informed decisions that are agreed upon by all stakeholders.

Overall, it is important to consider the specific needs and challenges of a project when developing a planning and control strategy, and to be flexible and adaptable in order to effectively cope with uncertainty. Collaboration can also be an important factor in the planning and control process, as it allows different stakeholders to share knowledge and perspectives and make informed decisions together

7.2.1.2 Relationship between these requirements

According to Expert 4, multiple levels of planning and control do not necessarily provide help with adaptability because subcontractors at the operational level who are not involved in reviewing milestones and constructability will not reflect flexibility in their contracts or detailed plans. Expert 2 believes that the construction stage specialists need to work together on constructability at the beginning of basic design, yet the two specialists have different views on when to constructability learning and who should be involved. Expert 2 believes that the construction manager and project control manager should be involved in constructability learning when the basic design is 20-30% complete, and that constructability learning is less effective when the design deliverables are too poorly completed. Expert 4 believes that subcontractors also need to be involved in this work and that conducting these constructability studies at an early stage, rather than when the contractor arrives on site, otherwise when the contractor is ready to start work, if problems are found, it can affect schedule and cost. However, Expert 4 was referring to the challenge of getting the contractor involved in constructability early originating from the owner and relating to the increase in cost at an early stage. Both experts agree, however, that collaboration is important for promoting adaptability and coordinating the interests and commitments of different stakeholders.

Expert 3, as the engineering manager, also emphasizes the importance of collaboration and continuous learning in driving adaptability. By working together with owners and other stakeholders, it may be possible to better understand and address the challenges and uncertainties that arise during the planning and control process. By promoting adaptability and flexibility in this way, it may be possible to better cope with changing circumstances and achieve the desired outcomes for the project.

7.2.1.3 Barriers and risks for implementation of this requirements

According to Expert 4, flexibility of subcontractors is a significant challenge for EPC general contractors in the planning and control process. To address this challenge, Expert 4 recommends that general contractors work with subcontractors early in the project to increase transparency and promote more flexible collaboration strategies (contracts) that foster trust and improve adaptability. However, many subcontractors may not be willing or able to be transparent and flexible with their business, which can create additional challenges for the general contractor.

To mitigate these challenges and increase flexibility, Expert 4 recommends defining constraints in advance, rather than when mobilizing to the site, and agreeing on timelines and contract dates with subcontractors. This aligns with the principles of pull planning, which involves proactively collaboration to introduce flexibility into the project execution plan that can quickly adapt to real-time demand information and reduce time and cost estimates compared to reactive planning methods. General contractors may find it useful to consider this strategy in order to better cope with challenges posed by owners.

Expert 3 also emphasizes the importance of the project manager's experience and management skills in facilitating success in the face of uncertainty. A project manager's attitude and understanding of uncertainty can influence their decision-making process and their ability to "make sense" of a situation and identify alternative actions.

Overall, the experts identified a range of requirements that can help to address uncertainty in EPC industrial construction projects, including multi-level planning and control, collaborative planning, constructability learning, reflective learning, and flexibility with adaptability. These requirements may be challenging to implement due to social behavior and other.

7.2.2 Review of the combination of LPS and Scrum

7.2.2.1 Completeness of the structure of the approach

The experts considered the structure of the approach to be complete and to include relevant management techniques or tools representing different requirements. Expert 4 suggested that the location of Pull planning needs to be reconsidered, as he suggested that all stakeholders need to plan collaboratively as early as possible, in addition, he believes that buffering is a waste and should not be reflected. Expert 2 also raised the same consideration of Pull planning location. Expert 1 believes that learning not only occurs at the end of the project, although it should not often occur for long periods of time as it can be time-consuming and expensive, but it should also still be conducted periodically and briefly during the project and be helpful at all levels of planning. Expert 3 believed that the execution plan should reflect feasible goals and feedback to each stage to ensure that the goals of each stage are consistent with the project goals.

7.2.2.2 Applicability of the combination of LPS and Scrum

Regarding the relevant elements of LPS and Scrum used in the approach, experts gave feedback based on their own experience of using them. For Engineering Expert 2, he stated that Scrum is the tool they are most familiar with and is the one that is applicable at this stage. He indicated that LPS is not fully used in the engineering stage because there is no Last planner in the engineering stage, and engineers are mostly involved in multiple projects. However, they use other features of LPS, such as Lookahead Planning, which is conducted with all professional leaders to ensure that the design work is carried out under a stable and manageable structure with common objectives and is very useful for learning and identifying constraints. Expert 1 expressed his preference for LPS that establishes processes and systems for the management of the entire project, as Scrum is difficult to keep track of everyone's commitment in the context of a larger organizational structure. He agreed that Scrum provides agility for self-governing teams of 5-8 people and is faster for problem solving. All the experts considered the social-behavioral challenges of the organization when evaluating the model and therefore provided adaptability, as well as the management aspects of the constraints, were not fully endorsed. They believed that the use of management techniques cannot completely avoid challenges from behaviors.

In short, experts have expressed confidence in the feasibility of the approach in industry. It is believed that the approach ensures that the planning and control process is more flexible in EPC construction projects, increasing the possibility of adjusting more quickly during project execution. And the approach must take into account the challenges from behavior in its application in order to make it produce better results.

7.2.3 Adjustment

Based on expert review and feedback, the approach was eventually modified in the pull planning, learning, and project execution plans. Pull planning for the project execution plan should begin no later than the beginning of the BOD stage, while learning should occur at each level and stage.

8. Discussion

The results of this research are discussed in this chapter. According to the DSRC of this research methodology, design science research is not only concerned with the applied utility of artefacts, but also with being able to contribute to the theoretical field of research. Section 8.1 discusses the practical relevance of the proposed approach,8.2 discusses the theoretical relevance of the research findings and 8.3 summarizes the limitations of the research.

8.1 Theoretical relevance

Research on effective planning and control of EPC (engineering, procurement, and construction) projects has theoretical relevance because it helps to improve our understanding of how to manage complex projects effectively. By studying different approaches to planning and control in EPC projects, researchers can identify best practices and techniques that can help to improve the efficiency and effectiveness of these projects. The theoretical relevance of this research lies in its ability to contribute to the body of knowledge on project management, specifically in EPC projects. It can help practitioners and researchers to better understand how to plan and control these types of projects, and to identify challenges and potential solutions. Additionally, research on planning and control in EPC projects can inform the development of new methods and tools for managing complex projects more effectively.

8.2 Practical relevance

The practical significance of this research is to design a planning and control approach that can improve the performance of EPC construction projects. The proposed approach involves extending the Last Planner System (LPS) to the entire execution phase of the project and incorporating best practices from Scrum and pull planning. This approach aims to better manage uncertainty in EPC industrial construction projects, which is a common challenge in these types of projects.

Traditional management approaches tend to focus on control, planning, and reducing uncertainty and change. However, this research highlights the need to adapt planning and control practices to varying degrees of uncertainty. The two main practical implications for improving EPC project planning and control identified in the case study are:

1. The need for more flexibility in EPC project planning and control: Quickly identifying and dealing with foreseeable uncertainties can help projects to be carried out more flexibly.

2. The importance of collaboration in EPC project planning and control: Collaborating

with all relevant parties from the early stages of the project can help to enhance cooperation in exploratory learning and adaptation and to jointly develop new solutions that meet different objectives. Collaboration can also increase trust and transparency, which can improve project performance.

8.3 The Quality of the Research

The research employed a triangulation approach (Guion et al., 2011), incorporating multiple data sources and utilizing both qualitative methods such as semi-structured interviews and expert review, to ensure the validity of the findings. The inclusion of diverse professional backgrounds among the selected experts and the focus on both the design theory and the approach itself aided in obtaining a comprehensive perspective. Observations of real-world project examples and conversations with project management participants helped to verify the practical relevance of the requirements extracted from the literature. The use of a qualitative approach in the expert review and interviews allowed for a more in-depth understanding of the phenomenon being studied, as well as the ability to analyze informants' perspectives in relation to literature theories.

This research has a few limitations that must be taken into consideration when interpreting the findings. One limitation is that the innovations for planning and control approach used in this research are limited to addressing different levels of uncertainty, which is the main type of complexity encountered in complex EPC construction projects. This means that the approach may not be suitable for addressing other types of complexity that may arise in these projects. Another limitation is that this research only examines the tactical aspects of the planning and control approach, such as the use of various techniques and tools to manage the project. The organizational aspects of the system, including the distribution of roles and responsibilities among different stakeholders, are not explored in detail. Additionally, the approach primarily focuses on the planning function, and the performance criteria and measures used in the control function are not extensively analyzed. Finally, the resulting approach needs to be tested for its effectiveness and usefulness in accordance with the requirements of design science research. However, due to time constraints, the evaluation of approach utility was not conducted in this research.

9. Closure

This chapter will conclude with a summary of the answers to the research questions in section 9.1. Based on the conclusion, section 9.2 gives recommendations for the solutions proposed in this research, including practical recommendations and future research recommendations.

9.1 Conclusion

This research aims to improve the planning and control techniques for complex EPC construction projects. To answer the main research questions, four sub-questions are posed. This section begins with the answers to the sub-questions and then completes the answers to the main research questions through four sub-questions.

9.1.1 Answers to Sub Research Questions

9.1.1.1 Sub-question 1: What are the challenges of the planning and control in the complex EPC industrial construction project?

One of the main challenges in the planning and control of complex EPC industrial construction projects is uncertainty. This uncertainty can be caused by factors such as the interdependence of activities, overlapping phases, a large number of disciplines and participants, dynamic and complex organizational structures, lack of complete information, and frequent changes. If these uncertainties are not effectively managed, they can negatively impact at least one project objective, such as cost, schedule, or quality. For example, if the engineering stage of an EPC industrial construction project does not accurately guide the execution of the project, it can lead to delays in the delivery of engineering deliverables and materials and equipment, resulting in low construction productivity, waste and rework, and increased costs. Delays in the use of industrial facilities can also result in delayed revenues for the owner. Therefore, it is important to focus on uncertainty management in the planning and control of complex EPC industrial construction projects.

9.1.1.2 Sub-question 2: What are the requirements related to planning and control approaches to address the challenges of complexity and uncertainty associated with EPC construction projects in the existing academic literature?

To address the challenges of complexity and uncertainty in EPC construction projects, there are several requirements related to planning and control approaches that are highlighted in the existing academic literature:

- Multi-level planning and control: In order to effectively manage complex and uncertain EPC construction projects, it is important to have a multi-level planning and control approach that takes into account the different levels of uncertainty and complexity that exist within the project.

- Collaboration planning: Collaborative planning and control approaches, such as those used in lean construction and agile management methods, can be effective in managing complex projects with uncertainty. These approaches involve collaboration between different stakeholders and frequent communication to ensure that project objectives are being met.
- Effective management of constraints: In order to effectively manage the constraints that can arise in complex EPC construction projects, it is important to have a systematic and structured approach to managing these constraints.
- Providing opportunities for learning: Building in opportunities for learning and reflection during the planning and control process can help to improve the effectiveness of EPC construction projects by enabling stakeholders to learn from their experiences and adapt to changing circumstances.
- Increasing transparency: Increasing transparency in the planning and control process can help to improve communication and coordination between stakeholders and can also help to identify and address potential issues more effectively.

9.1.1.3 Sub-question 3: How can these identified requirements be effectively implemented in an EPC construction project?

To effectively implement the identified requirements in an EPC construction project, it is necessary to adopt a more flexible approach to planning and control. This can be achieved by quickly identifying and addressing foreseeable uncertainties and by collaborating with all relevant parties from the early stages of the project. The case study demonstrated that this approach, which involves using LPS, Scrum and engaging in collaborative communication and exploratory learning, can be successfully applied to the construction stage. It can improve understanding of the benefits of using Scrum, facilitate effective communication, and increase the effectiveness of guidance and daily meetings provided by Scrum master. It is important that effective implementation of requirements in an EPC construction project requires a combination of flexibility, collaboration, and the use of tools and techniques such as LPS and Scrum to support effective planning and control.

9.1.1.4 Sub-question 4: How can an integrated planning and control approach be developed?

An integrated approach to planning and control can be designed and evaluated through design science research using both theoretical and practical knowledge. The designed approach contains the basic requirements for effective planning and control of EPC construction projects, as well as mechanisms for effective application of these requirements to practice and enhanced technical tools that combine LPS and Scrum.

In the opinion of experts, the identified requirements for effective planning and control in EPC industrial construction projects are applicable and useful in addressing uncertainties. They also noted that the structure of the approach, which includes relevant management techniques and tools, is complete and can be further adapted to fit the specific needs of a project. The experts expressed confidence in the appliablity of the approach in the industry, as it can help to ensure a more flexible planning and control process that is better able to adjust to challenges and changes during project execution. However, they also emphasized the importance of considering the behavior of all relevant parties, including subcontractors and the project owner, in order to fully realize the benefits of the approach. Overall, it seems that the identified requirements and the integrated planning and control approach can be effective in improving the planning and control of EPC construction projects when applied in a systematic and adaptable manner.

9.1.2 Answer to Main Research Question

Finally, with the help of the answers to the sub-questions, the main research question defined for this research can be answered. The main research question was as follows:

How to effectively plan and control complex EPC industrial construction projects?

This research supports the effective planning and control of EPC industrial construction projects by developing an integrated planning and control methodology. The basic requirements of the proposed approach were derived from a literature review of the EPC environment, which included an analysis of different planning and control techniques (CPM, LPS and Scrum) to cope with complexity and uncertainty. Based on an empirical study of an A/E/C company adopting the Lean concept and one of its EPC industrial facility projects, the initial set of requirements was refined to consider the specific environment of an EPC industrial construction project. This specific refinement was guided by providing several mechanisms and techniques (a combination of LPS and Scrum) that could be associated with the six requirements to guide their implementation. The proposed approach was evaluated through interviews with industry experts and was found to be applicable and effective in the EPC construction industry. The combination of structured and agile approaches enabled the complexity and uncertainty of EPC projects to be effectively managed and contributed to project performance. This research provides practical recommendations for practitioners and researchers in the field and suggests that further research is needed to validate the proposed approach in different environments and different types of EPC projects.

9.2 Recommendation

This section makes recommendations for practice (9.2.1) as well as further research (9.2.2).

9.2.1 Recommendation for practice

This section presents information on practical recommendations that can be used by EPC general contractors. As all empirical data was collected in Organization D, the results of this research do not provide an industry-wide overview. The practical recommendations presented in this report can be tried and tested by other organizations.

- Interviewees highlighted the importance of client support for the full application of the approach. Therefore, it is recommended that Involve clients in the full implementation of the proposed approach to ensure their support. To do this, organizations can focus on building a positive corporate image through successful case studies, a strong corporate culture, professional staff, and financial stability to increase competitiveness.

- Interviewees emphasized that the application of the approach requires the efforts of the right people, so improving the management capacity of key project managers is a top priority, with the thinking and competencies of key managers again being the key core. Therefore, invest in the development of key project managers to improve their management capacity. This includes encouraging them to be open to new ways of thinking and experimenting with different approaches to problem-solving, which can bring about innovation in the business.

- Interviewees noted that the detailed engineering design of some EPC projects is carried out by specialist subcontractors, so the experience and expertise of subcontractors has a significant impact on project performance. Therefore, carefully select subcontractors with relevant expertise and experience, and optimize decision-making processes to ensure the most cost-effective design solution. Additionally, consider the subcontractors' familiarity with new management methods and technologies to ensure their commitment to project implementation management.

The proposed approach in this research uses a combination of LPS and Scrum techniques, and recommendations for the use of these techniques include:

- Provide training and support to project managers and other team members to ensure they understand the principles and practices of the Last planner system and scrum, and how to apply them effectively in the project context.

- Set clear expectations and goals for the use of the LPS and Scrum and establish accountability measures to ensure that team members are following the prescribed processes and practices.

- Foster a culture of transparency and collaboration within the project team, as this can help to build trust and commitment among team members and improve the chances of success for the project.

- Regularly review and assess the effectiveness of the Last planner system and scrum in the project context and make adjustments as needed to ensure that they are meeting the needs of the project and the team.

- Use data and analytics to track the performance of the project and identify areas for improvement in the use of the Last planner system and scrum. This can help to identify any issues that may be hindering the effectiveness of these methods and allow for corrective action to be taken.

- Consider seeking guidance and support from experienced professionals or consultants who have expertise in the use of the Last planner system and scrum in construction projects.

9.2.2 Recommendation for future research

The evaluation of this research demonstrated the significance of the proposed approach in the construction industry. However, further research is necessary to fully understand the practical implementation and potential for further development of the approach. In order to build upon the findings of this research, the following areas of investigation should be considered:

- Extension of the approach to a wider range of projects, including large infrastructure projects, to assess its applicability across different project types.
- Evaluation of the impact of different forms of payment EPC contracts on the success of approach implementation, as these contracts can create different conditions that may support or hinder collaborative working conditions in projects.
- Investigation of the effectiveness of the approach in construction-led projects, where the design expertise, optimization, and synergy capabilities of the construction unit may not play a significant leading role.
- Exploration of the attitudes and practices of traditional construction companies towards transitioning to advanced techniques and management approaches, such as those proposed in this research.

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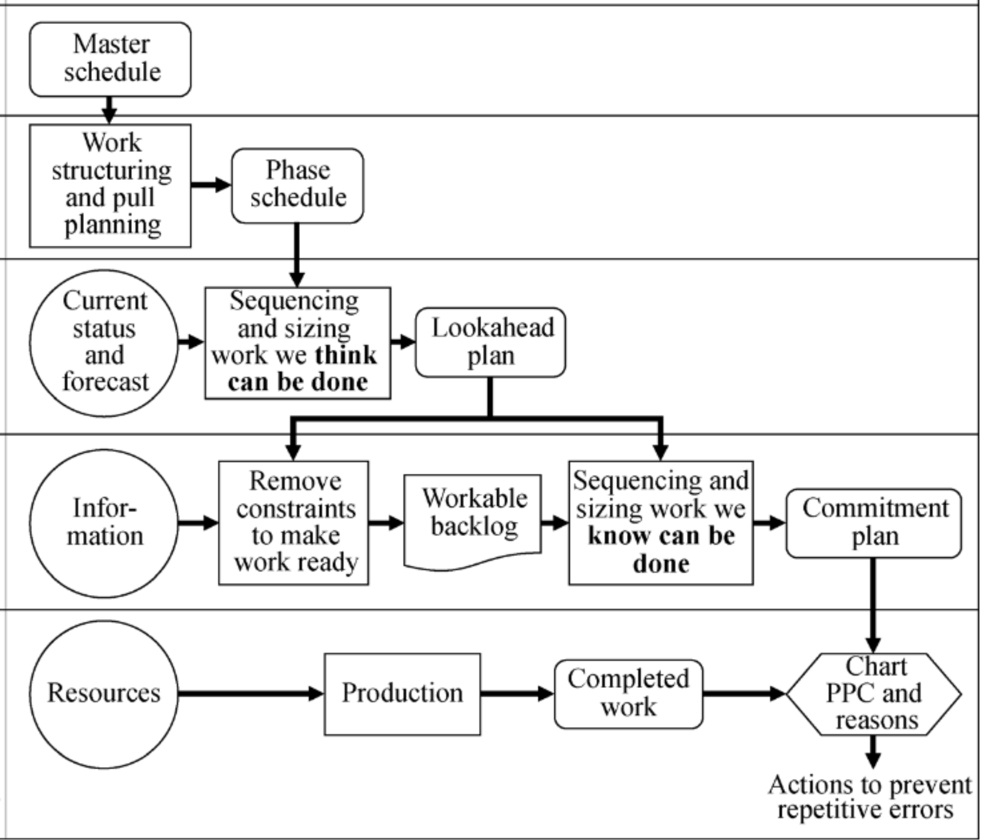
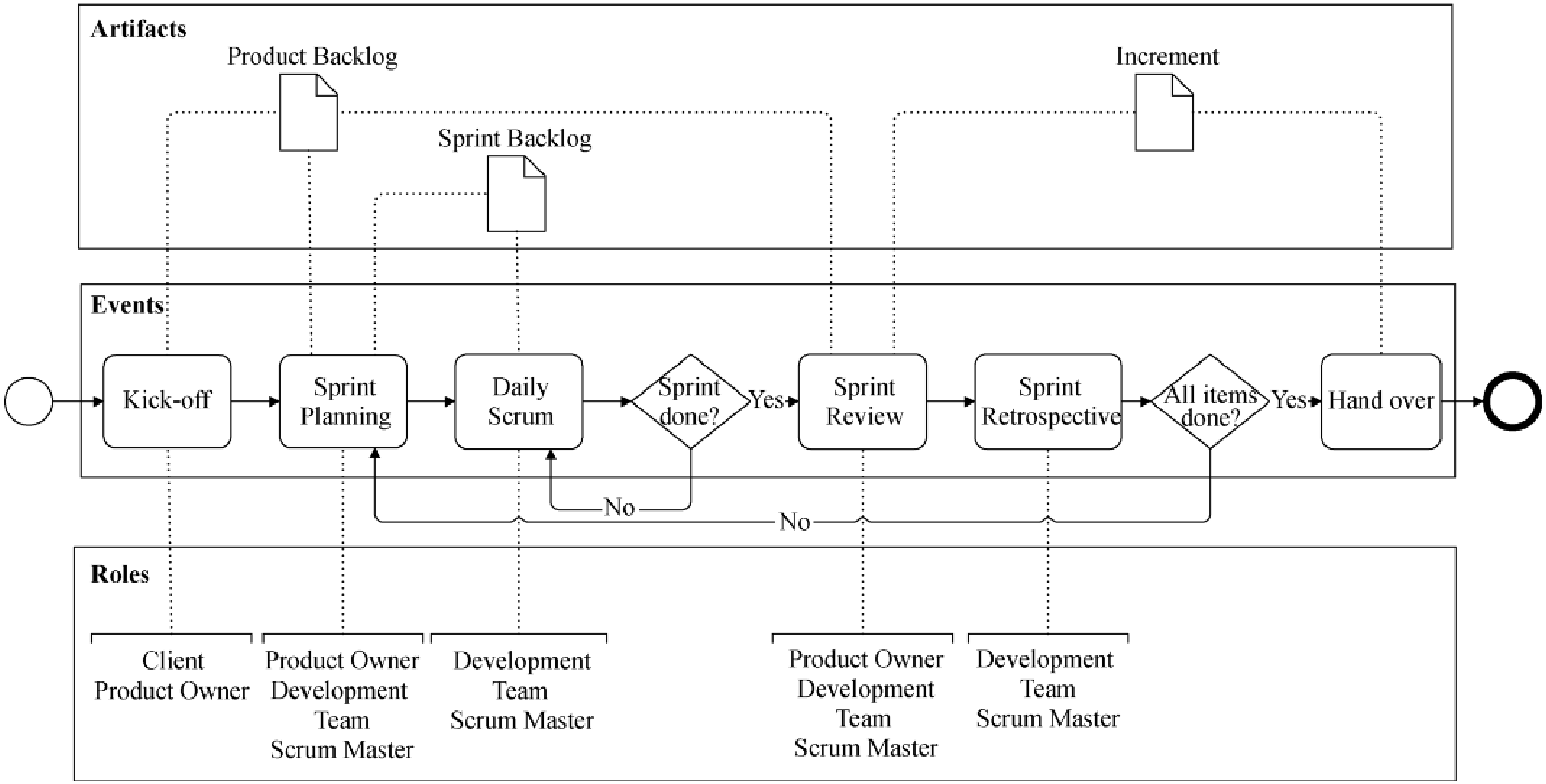
Appendix A1 **Overview of the LPS planning levels and related process (adapted with permission from Ballard (2000))**

	Planning level	Function
As needed	**Master scheduling** [Should]	• Set milestones, phase durations and overlaps
As needed	**Phase scheduling** [Should]	• Specify handoffs and conditions of satisfaction among processes within phases
Weekly	**Lookahead planning** [Can]	• Identify and remove constraints • Breakdown tasks from processes into operations • Design operations
Weekly	**Commitment planning** [Will]	• Make reliable promises
Weekly	**Learning** [Do]	• Production • Measure PPC, TMR and TA • Find root causes for issues and define countermeasures • Act to prevent reoccurrences

Process view



Appendix A2 Scrum process and related elements (Poudel et al., 2020)



Appendix A3 Summary of the Comparison between Last Planner System and Scrum

Dimension	LPS	Scrum
1. Origins	• In the construction industry • Based on Lean production principles	• In the manufacturing and software industry • Aligned to the *Manifesto for Agile Software Development*
2. Main purpose	• Increase value for the customer while reducing waste	• Deliver products of the highest possible value for the customer
3. Overall system/framework process	• All activities necessary to complete the project are broken down and refined through the different planning levels • Proactive identification and removal of activity constraints • Sequencing and sizing of work based on reliable promising to improve workflow derive in the WWP • Analysis of plan failures for continuous improvement	• Everything needed to deliver the product (requirements) is managed, refined, and prioritized in the Product Backlog • Team commits to work on specific Product Backlog items deriving the Sprint plan • The team works to deliver product increments iteratively • Analysis of Sprint experiences for continuous improvement
4. Tools or artifacts maintained by the team	• Master schedule • Phase schedule • Lookahead plan • Workable backlog • WWP	• Release plan • Product Backlog • Sprint Backlog • Increment
5. Team composition and main roles	• "Last planners" who are knowledgeable team members providing inputs about how to optimally perform the work (e.g., construction specialists, frontline supervisors, craftsmen) • Number not specified	• Product Owner • Development Team • Scrum Master • Recommendation of less than nine team members
6. Regular events or team meetings	• Planning meetings (cadence not strictly defined for different planning levels) • WWP (planning and review) • Daily huddles	• Envisioning (Product Planning) • Scrum Release Planning • Sprint Planning (cadence according to Sprint duration for every Sprint) • Sprint Review • Sprint Retrospective • Daily Scrum
7. Metrics/Dashboards	• PPC • TMR • TA • Frequency of plan failures • Visual controls to consolidate and share project information	• Velocity • Task Board • Sprint Burnup Chart • Sprint Burndown Chart • Information Radiators to consolidate and share project information
8. Approach to learning	• Analysis of Frequency of plan failures • 5 Whys, Plan–Do–Check–Act, Detect–Correct–Analyze–Prevent	• Sprint Retrospective

Source:(Poudel et al., 2020)

Appendix B1 Interview Guidance

Part 1 Contextual survey	Main questions	Goal
Interviewee	1) What is your formal role/position title within your organization and the project? 2) What tasks/responsibilities do you have in that role? 3) How long do you have within your role? 4) Which planning and control methods have you ever worked with? Critical Path Method (CMP)/Critical Chain (CC) /LPS/Scrum/Hybrid 5) If you do not work with CC, LPS or Scrum before, do you know these methods? How do you know them? 6) If you ever worked with CC, LPS or Scrum, how many projects have you ever worked with?	Identify the expertise of the participants
Project	1) What is the name of the project? 2) What type of the contract of this project? 3) What is the goal of the project as defined in your organization? 4) What is the status of the project? 5) What planning and control methods does the project use?	Identify whether the case meets the criteria of the case study.
Part 2		
Problem identifies	1) Why was LPS chosen to use as a main method? 2) Do you think the exist planning and control of the project useful? Why? 3) What is the main problem do you think in this project? 4) What is the reason for this problem?	Explore the planning and control process and techniques used in the project
Project Complexity	1) Do you think the project complex? Explain it. 2) Did the characteristics and complexity of the project influence the planning and control of the project? How?	Understand the research problem
Practices	1) Which functions and tools of LPS were used for the planning and control of this project? 2) How did you prioritize tasks? What were the criteria and how is it estimated?	Explore the project-level operation of the hybrid mechanism

	3) Daily meetings: How did you configure these meetings? Was this beneficial? Why?	
	4) What was the added value of the white board?	
	5) Sprint or Lookahead: How long is the sprint or lookahead? Why was this duration adequate (or not)?	
	6) Could value be added in each sprint? What is the added value of sprint reviews or LPS learning? (How do team members learn from these reviews?)	
	7) How close was the client involved during the project? In what way did this influence the planning and control of the project?	
	8) How is the progress/earned value of projects monitored and reported when using a combination of different methods for planning and control?	
Effectiveness of the planning and control	1) Were these methods a good choice for planning and controlling the project? If not, what other planning and control method would have been better?	Main research question
	2) How do you think these methods have improved the success of the project most	
	3) Could the approach be effective in supporting the planning and control of EPC projects?	
	4) Which practices do you think have the greatest impact on project planning and control and project success? And which practices do you think are the least effective?	Find opportunities to develop the approach

Appendix B2 Scrum implementation

Implementation-Application Scrum element to facilitate LPS in construction stage of an EPC project

As a result of planning unreliable in the engineering phase, the constructability of the steel installation was not met, the start was delayed and the idling of steel installation equipment, materials and personnel would lead to waste and increased costs and delay subsequent critical work. And this error occurred mainly because the decisions made in the early planning stages were made by the engineering staff and did not consider the actual construction needs (Figure 17). The error here was therefore discovered during discussions with the construction team during the lookahead planning meeting. The construction team adapted and implemented Scrum to address the issues of constructability of the concrete and steel works.

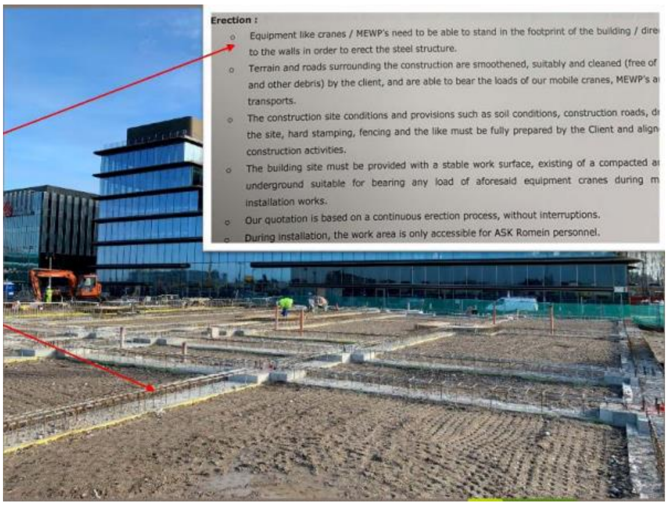
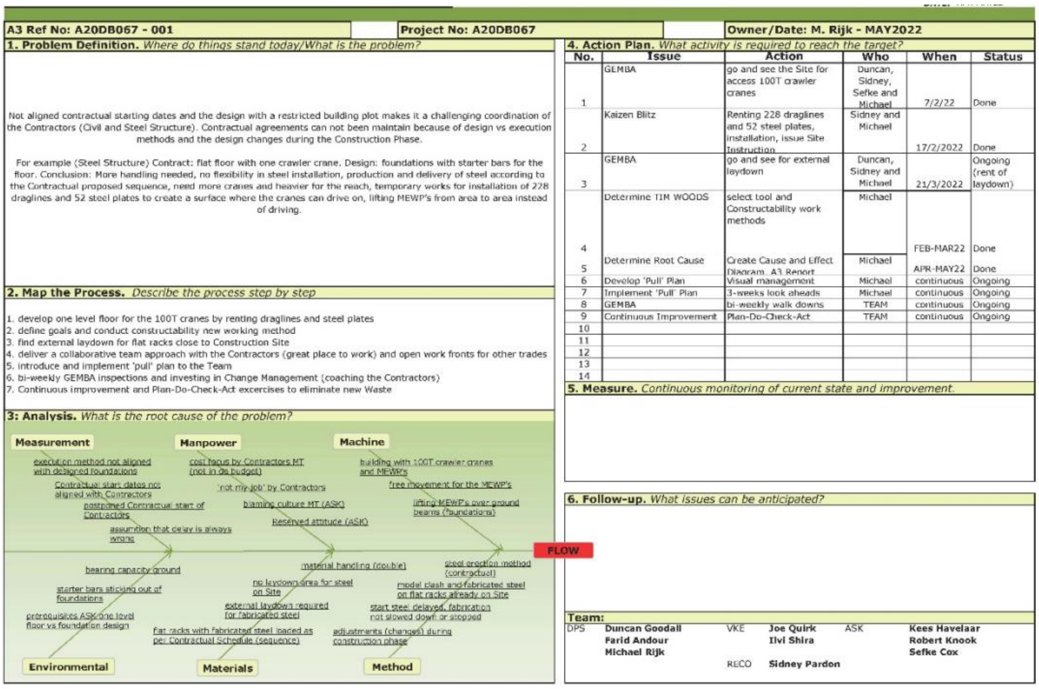


Figure 17. Constrains for steel works

The construction management team, together with the 'Product Owners' - steel contractor, concrete subcontractor, site facility subcontractor and scheduler - formed a Scrum team to undertake Sprints to deliver the highest possible value to the owner product - to provide in time and safe constructability of the steel work.

During the sprint planning workshop, the construction manager still uses the master schedule as a baseline and makes decisions (developing products) with the site superintendent via S.M.A.R.T. The sequence of work was re-adjusted based on the work area and the expertise of each team member was then used to make improvements. The revised standard sequence would provide the customer with a list of means to install the steel safely, quickly, and efficiently according to the schedule they have outlined in the contract schedule and registered in the Action plan (Product backlog) (Figure 18). This list was always evolving according to the changing needs of the stakeholders and the feedback received during the sprint.



A3 Ref No: A20DB067 - 001

Project No: A20DB067

Owner/Date: M. Rijk - MAY2022

1. Problem Definition. *Where do things stand today/What is the problem?*

Not aligned contractual starting dates and the design with a restricted building plot makes it a challenging coordination of the Contractors (Civil and Steel Structure). Contractual agreements can not been maintain because of design vs execution methods and the design changes during the Construction Phase.

For example (Steel Structure) Contract: flat floor with one crawler crane. Design: foundations with starter bars for the floor. Conclusion: More handling needed, no flexibility in steel installation, production and delivery of steel according to the Contractual proposed sequence, need more cranes and heavier for the reach, temporary works for installation of 228 draglines and 52 steel plates to create a surface where the cranes can drive on, lifting MEWP's from area to area instead of driving.

2. Map the Process. *Describe the process step by step*

1. develop one level floor for the 100T cranes by renting draglines and steel plates
2. define goals and conduct constructability new working method
3. find external laydown for flat racks close to Construction Site
4. deliver a collaborative team approach with the Contractors (great place to work) and open work fronts for other trades
5. introduce and implement 'pull' plan to the Team
6. bi-weekly GEMBA inspections and investing in Change Management (coaching the Contractors)
7. Continuous improvement and Plan-Do-Check-Act excercises to eliminate new Waste

3: Analysis. *What is the root cause of the problem?*

4. Action Plan. *What activity is required to reach the target?*

No.	Issue	Action	Who	When	Status
1	GEMBA	go and see the Site for access 100T crawler cranes	Duncan, Sidney, Sefke and Michael	7/2/22	Done
2	Kaizen Blitz	Renting 228 draglines and 52 steel plates, installation, issue Site Instruction	Sidney and Michael	17/2/2022	Done
3	GEMBA	go and see for external laydown	Duncan, Sidney and Michael	21/3/2022	Ongoing (rent of laydown)
4	Determine TIM WOODS	select tool and Constructability work methods	Michael	FEB-MAR22	Done
5	Determine Root Cause	Create Cause and Effect Diagram, A3 Report	Michael	APR-MAY22	Done
6	Develop 'Pull' Plan	Visual management	Michael	continuous	Ongoing
7	Implement 'Pull' Plan	3-weeks look aheads	Michael	continuous	Ongoing
8	GEMBA	bi-weekly walk downs	TEAM	continuous	Ongoing
9	Continuous Improvement	Plan-Do-Check-Act	TEAM	continuous	Ongoing
10					
11					
12					
13					
14					

5. Measure. *Continuous monitoring of current state and improvement.*

6. Follow-up. *What issues can be anticipated?*

Team:

DPS	**Duncan Goodall**	VKE	**Joe Quirk**	ASK	**Kees Havelaar**
	Farid Andour		**Ilvi Shira**		**Robert Knook**
	Michael Rijk				**Sefke Cox**
		RECO	**Sidney Pardon**		

Figure 18. Action plan

This planning requires the cooperation of all members of the team to achieve. The construction manager identified the activities to be completed during the week (Sprint Backlog) based on the revised work order, schedule and action plan and assigned the relevant tasks to each member and registered them on a whiteboard (see Figure 19). The Site Superintendent acted as the Scrum Master, looking after the interests of all members and ensuring that the development team has all the necessary resources to effectively complete the tasks assigned to them and to resolve any issues that arise during the sprint. The Construction Manager ensured that the project meets all schedule and financial requirements.

Figure 19. Daily meeting

Daily meetings followed a Plan-Do-Check-Act approach. The team discussed the day's work and plans the work for the next 24 hours. The superintendent also checked the progress on the whiteboard, i.e., the work completed since the daily meeting, to ensure that tasks were actually completed and removed the whiteboard and that any tasks not completed will continue to be backlogged for the next sprint. Constraints were identified and discussed daily as to when they need to be removed and who will remove them. After the construction site check, it was resolved on-site in time. This approach optimized performance and promoted better cooperation between team members.

At the end of each weekly sprint, met with the project owner, engineering team and subcontractors to review the work of the sprint together, received feedback from each participant and discuss changes or new requirements based on the feedback. The team used the feedback received to plan their next sprint.

Result

The level of participation in the daily Scrum meetings on the project was high, the level of collaboration between the different members of the team was improved by the coordination of the Scrum master, participation in the daily meetings was active in decision making, planning became less centralised, and subcontractors became more involved in completing tasks. The design activity involved a weekly six-week lookahead-looking interactive planning cycle to achieve collaboration and interaction, with agreed two-week work batches for each discipline. Each discipline runs their own Scrum committee and is more engaged in completing their own sprint.

Scrum provides the flexibility to make decisions in the face of change and uncertainty more responsive and manageable. scrum teams work in a more self-organized way. The development team decides what tasks to do based on the changing needs of the customer in interaction with other team members and stakeholders. The team can make decisions faster and more efficiently using the applicable decision methods and can also develop different processes depending on the goals and tasks. As in Part 1, the team used the S.M.A.R.T. method to define the problem, make several alternatives and finally choose the most feasible one. this inherent flexibility of the Scrum framework allows Scrum to be implemented quickly throughout the project and throughout the organization. design activities in Part 2 form Scrum teams based on specialisms making design batches smaller and more acceptable and handle change.

The approach provides learning opportunities. in Part 1 the scrum team monitors deviations through the "plan-do-check-act" (PDCA) approach, measures results, sprint reviews are analyzed in conjunction with LPS indicators and, where necessary, a "pull" plan is initiated to align objectives with the reality on the construction site. the PDCA approach is not only carried out at the end of each sprint, but also at the short-term plan level (daily) for improvement, analyzing the reasons for not completing the plan the previous day and taking corrective action.

Concrete construction was accelerated, and the steelwork installation was delayed by two weeks to start, but good workability was provided on site during construction, ensuring that the steelwork installation was carried out quickly and efficiently without disrupting the critical path or delaying the original substantial steelwork completion date for the whole project. Prior to the implementation of the sprint, the construction management team anticipated significant delays and increased costs as a result of not commencing the steelwork installation in time. On the one hand, it was necessary to wait for the concrete to be completed before the steelwork could commence in accordance with the implementation plan, and on the other hand, inefficient work was carried out during the installation process due to problems with the junction with the concrete work. On the other hand, after implementing the constructability offered to the steelwork contractor by Scrum Management, the cost was €123,548, a saving of almost 58% compared to the contractor's quotation due to the initial delays (Figure 20). The delay in the installation of the steelwork as originally planned would have resulted in an expenditure of €293,328.

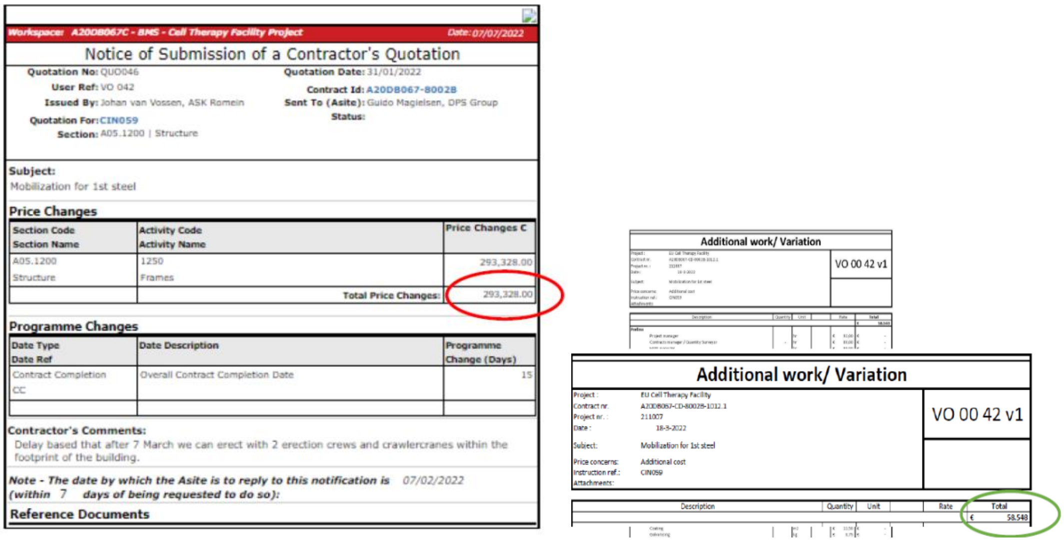
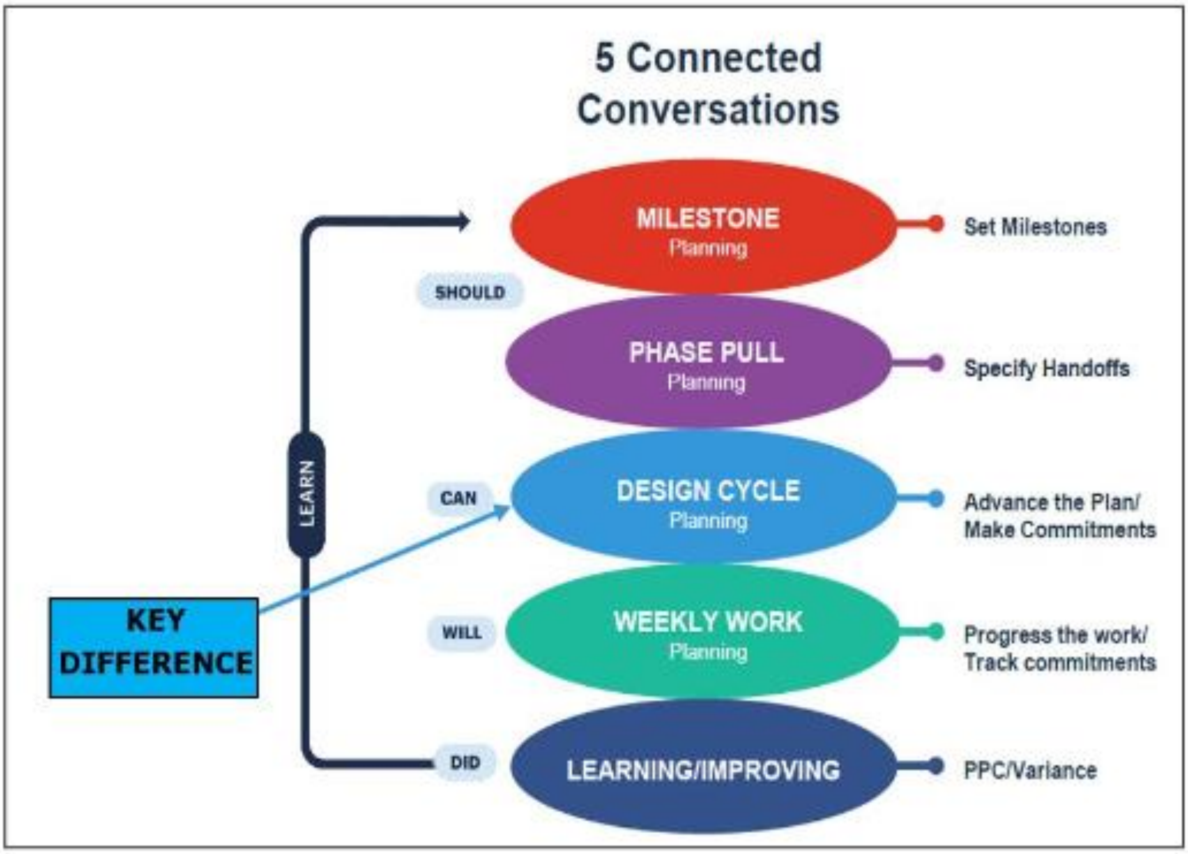


Figure 20. Cost comparison

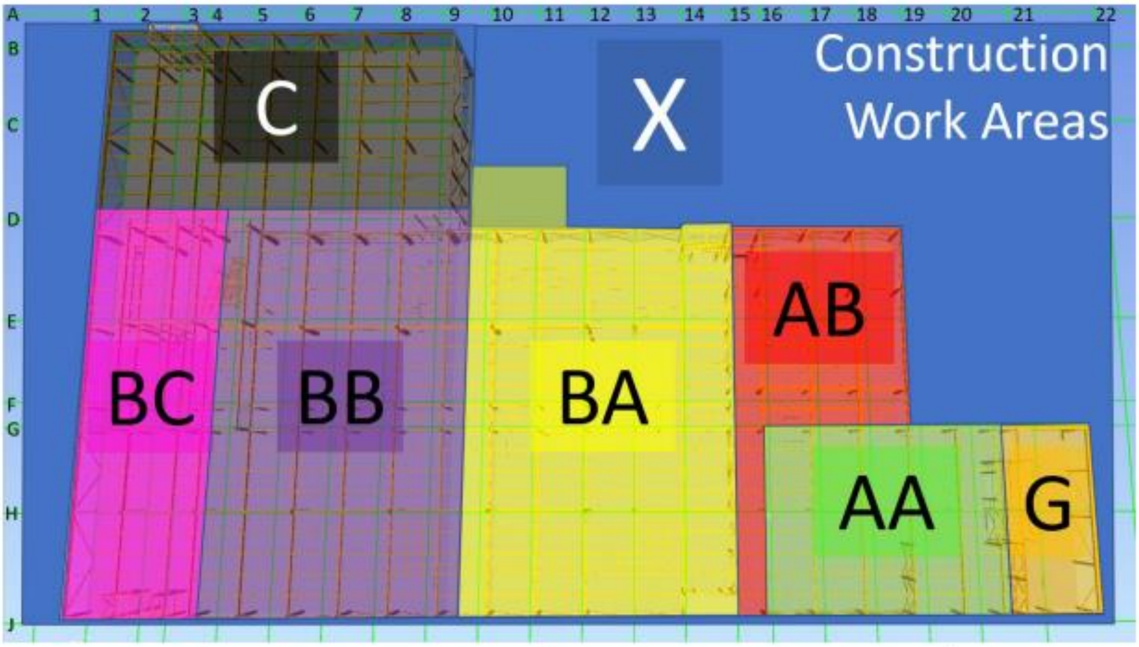
LPS and Scrum in Design Implementation

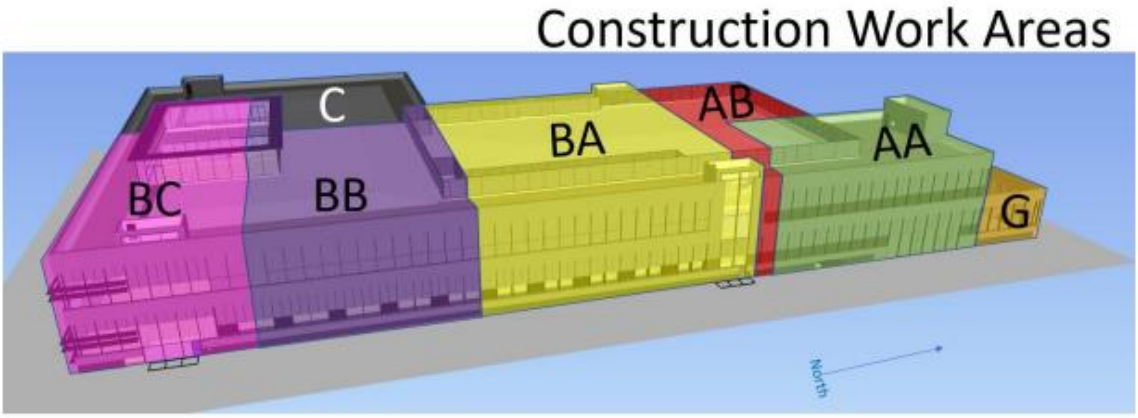


While some adaptations have been made, the Five LPS Planning Conversations remain the same except the Look-ahead Planning Conversation shifts to Design Cycle

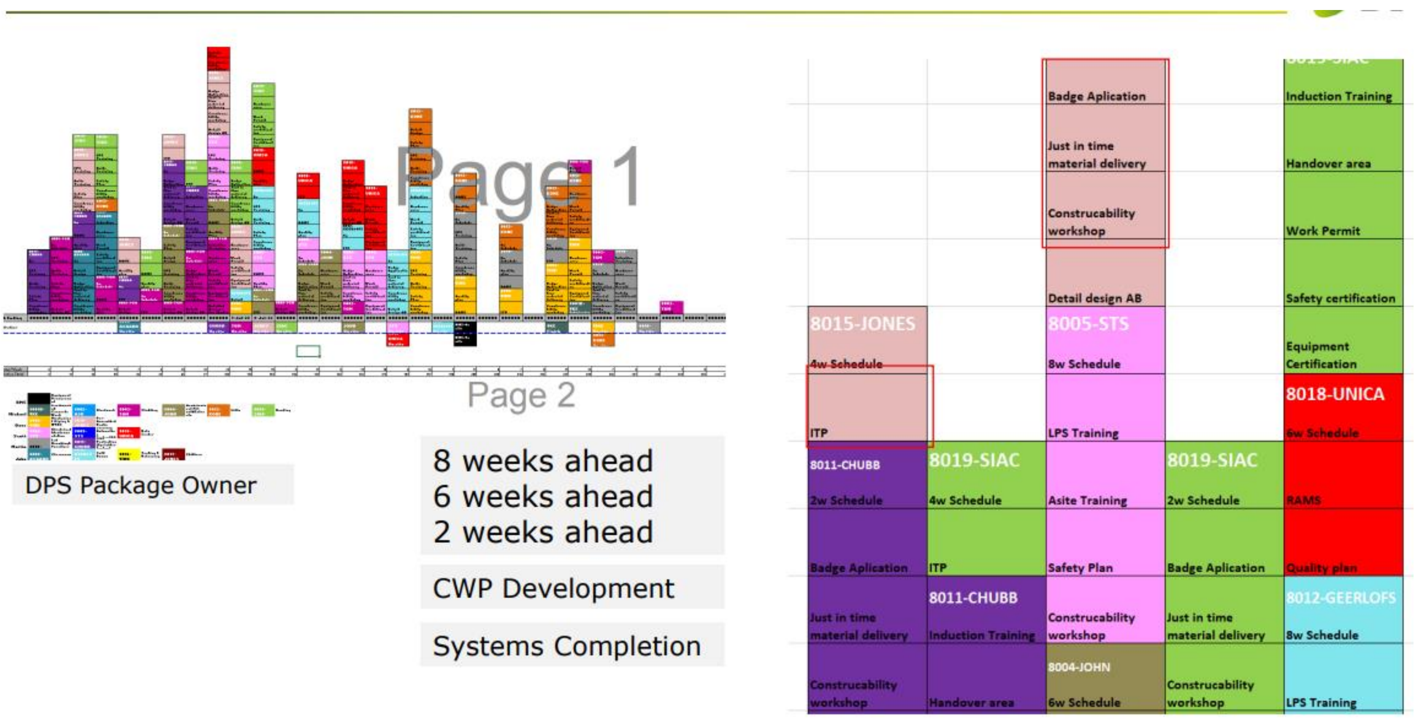
Planning. Also, instead of the traditional weekly work plan or commitments log, DPS Group utilise a Sprint Backlog to generate a two-week batch of design work. All design disciplines engage with the six-week look-ahead interactive planning cycle conducted weekly. Handoffs and interactions are agreed and a two-week batch of work per discipline is agreed. Each discipline proceeds to run their own Scrum board to complete their own sprint.

Appendix B3 Construction Work Areas





Appendix B4 Construction Skyline



Appendix C Expert Review Guidance

Part 1 Contextual survey

Part 1: Contextual survey	
Interviewee	1. What is your formal role/position title within your organization and the project?
	2.What tasks/responsibilities do you have in that role?
	3.How long do you have within your role?
	4.Which planning, and control methods have you ever worked with? Critical Path Method (CMP)/Critical Chain (CC) /LPS/Scrum/Hybrid
	5.If you do not work with CC, LPS or Scrum before, do you know these methods? How do you know them?
	6.If you ever worked with CC, LPS or Scrum, how many projects have you ever worked with?

Part 2 Introduction and discussion the design requirements

Step 1 Introduction

Begin by introducing the expert to the topic, purpose and expected results of this research, so that the expert has an idea of the purpose of the questions to be asked next in order to give the correct response.

Step 2 Questions

The interview questions were described in detail below:

Subjects	Questions	Objective
Insight of the planning and control in EPC projects	1) What is your understanding of the planning and control of projects? 2) What current practices or trends have you observed in the planning and control of industrial construction projects?	
Reflection of the identified	3) What needs have been considered in the planning and control process for the project?	The objective of this subject is to review the performance of

requirements implements in the case project	4) What do you think was done well in the planning and control of the project and what needs to be improved? 5) Do you have any examples of what is done in practice regarding the identified requirements? 6) Are there any requirements that you are aware of that are not mentioned?	the projects analysed by the authors in the case study in order to further validate the results of the case study. The design requirements used to support the construction of the approach are detailed to experts in this subject.
Review of the refine requirements	1) What do you think is the relationship between these requirements? (Are they relevant?) Which requirements are important? 2) What do you consider to be the prerequisites (enablers) for meeting these requirements? (technique / people / organization) 3) What difficulties/obstacles do you see in the implementation process? How do you think they can be solved?	The objective of this subject is to assess the relevance of the identified requirements and potential problems in their implementation.
Planning and control techniques in practice	1) What planning and control techniques are you aware of being used in EPC industrial construction projects? How do they relate to the requirements identified? 2) What are your views on the use of Lean and Agile and their associated tools in construction projects? How do they relate to the requirements identified? 3) Do you have any examples of good practice that you are aware of that would be useful for EPC industrial construction projects?	The aim of this subject is to understand the use of planning and control techniques in the industry and the practical application of these techniques.

Step 3 Close

Part 3 Introduction 1st Vision of the approach

The main objective of the construction of the approach is to improve the effectiveness of the planning of the initial stage of project execution (engineering stage) to achieve constructability as soon as possible and to enhance the control of the production construction stage, thus making sure that the project objectives are achieved.

The approach is broken down into EPC project execution stages consisting of three basic stages: engineering stage, procurement stage, and construction stage. Each stage includes recommended methods or elements to accommodate the management of each phase.

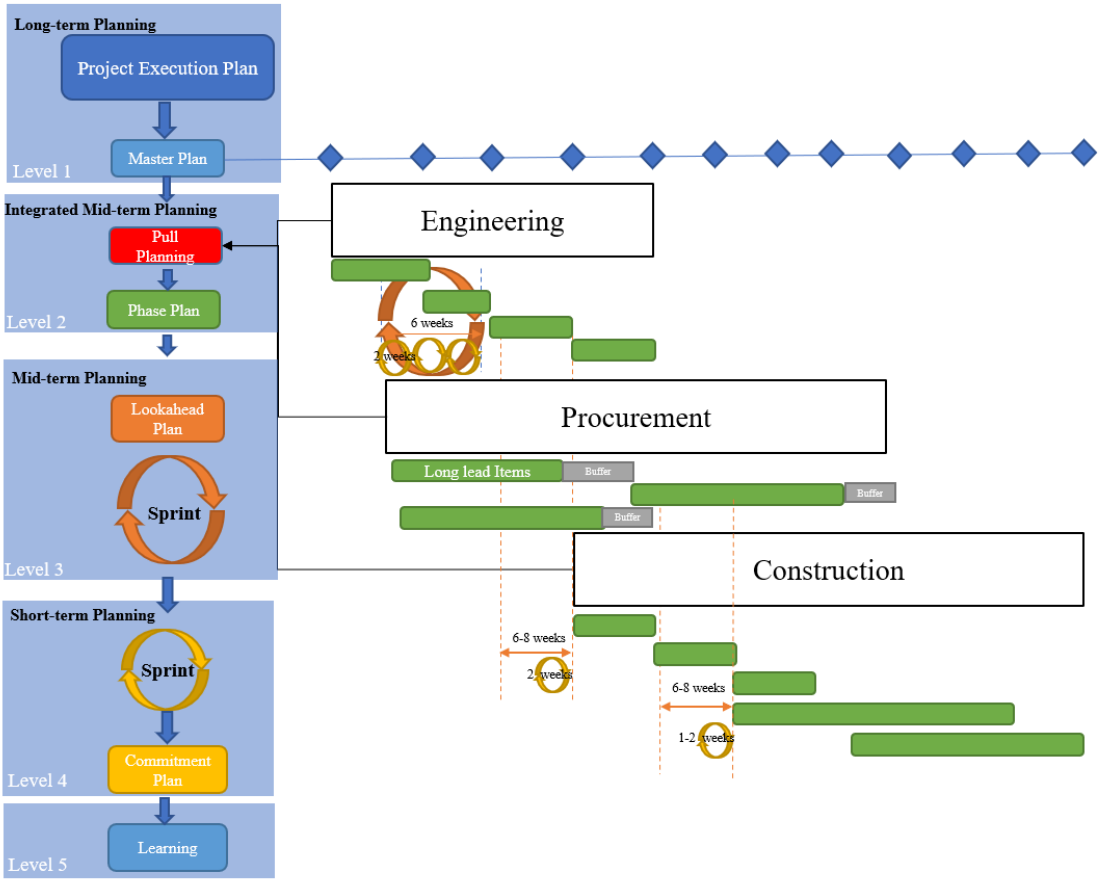


Figure shows an overview of the proposed design planning and control approach. According to the integration mechanism proposed in 4.3, LPS acts as the main methodology of the approach, incorporating some key elements of CC, Scrum for synergy. Therefore, the five planning hierarchical levels of LPS remain in place. The five levels of planning and control have been adapted to the different stages of the EPC project. In this section, the different stages of the approach are described.

At the end of each sprint phase, a review meeting should be held, which should include project participants from the design and construction teams. The meeting should jointly review the work of the sprint phase and receive feedback from each participant and discuss changes or new requirements based on the feedback. The design team and construction team should use the feedback received to plan their next sprint.

Evaluation form

	Evaluation criteria	**Strongly Disagree**	**Slightly Disagree**	**Neither Disagree nor Agree**	**Slightly Agree**	**Strongly Agree**
Structure level	**The technical elements used in the approach in combination adequately reflect the following requirements**					

	Muti-level planning and control	R01					
	Collaboration planning	R02					
	Effective management of constraints	R03					
	Providing adaptation	R04					
	Provide opportunities for learning	R05					
	Increase transparency	R06					
	The technical elements used in the approach in combination are relevant to the EPC construction projects						
Practice level	**The technical elements used in the approach in combination are easy to use**						

Evaluation questions

Some questions will be asked to get more detail views about the evaluation form.

	Questions	Responds	
1	Does the proposed approach is feasible?	Agree	Disagree. Please give reasons.
2	Did it help the organization to planning and control the project delivery process? How and to what extent? / Why not help?		
3	Do you feel that this approach is applicable and useful in the industry?	Yes	No, please give some reasons.
4	Could the approach be made more useful? How?		
5	Could the approach be made more practical? How?		
6	What difficulties/obstacles do you see in the implementation process? How do you think they can be solved?		