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Implementation of Lean and Last Planner System® in the construction industry in Norway

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Master of Science in Engineering Structures and Materials
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Preface

This master thesis completes my five year as student at the University of Stavanger, with a degree in Master of Science in Engineering Structures and Materials at the Faculty of Science and Technology. The thesis is written in collaboration with Backe Rogaland AS.

Lean is a popular word when talking about productivity and quality. People learn about Lean in all kinds of workplaces, both in information technology as well as in hospitals. All this talk about Lean interested me to researching how it is used in the construction industry. After looking into the subject, I understood that Lean is a well-known word in the industry. However, it seems as the implementation is not to the degree it can be utilized.

I would like to thank my supervisors Samindi Samarakoon and Chandima Mudiyanselage for their guidance and help. Thank you Backe Rogaland AS for giving me the opportunity to observe the Ledaal Park project. Engineer Alisa Nilsen, thank you for sharing your thoughts and knowledge. Appreciations to engineers Birgitte Kielsen and Caroline Austbø for sharing your knowledge and ideas. Finally, thanks to my informants for letting me interview you and for sharing your experience and knowledge.

Summary

Construction industry has been relatively less productive compared to the manufacturing industry in mainland Norway. In order to improve the productivity in the construction industry the industry must change. The traditional way of planning projects might not be efficient enough in the future. Lean has proven to be a method that increase productivity and decrease the need for storage in other industries. Lean construction refers to how the Lean methods can be used in the construction industry.

In Norway, a few companies have started implementing Lean into their projects. This thesis is a collaboration with Backe Rogaland AS to investigate their use of Lean and the Last Planner Systems. Furthermore, this thesis suggests certain changes utilizing the Lean and the Last Planner Systems to Backe Rogaland AS Ledaal Park project. The proposition is aimed to improve the planning process of this project, or to be of use in later planning of projects.

The literature review performed gather knowledge about Lean and Last Planner System relevant to the construction industry, and insights to how these methods can be used in construction projects. Research papers were analysed to understand the current use of Lean in the construction industry in Scandinavia through certain project described. In addition, the thesis has obtained an interview with Total Betong AS to get insight into an example of successful implementation of Lean and Last Planner System.

The thesis has carried out a case study to gather information about the planning process in one of Backe Rogaland AS projects, Ledaal Park. The case study includes observing meetings, conduct unstructured interviews, and study documents in the Ledaal Park project.

This thesis use data from the Ledaal Park project to make an Excel worksheet, as well as a BIM model in Synchro software. The results from this thesis study suggest improvements made in the Excel worksheet, and a project file in Synchro software. The Excel worksheet is based on Lean and Last Planner theories, and are aimed to optimize the plans made in the Ledaal Park project. The Excel worksheet presents an improvement in contrast to the many documents the project uses today. The usage of data shown in this thesis will by collecting all documents in the same worksheet, reduce time spent on managing.

This thesis use of Synchro software show how digital technology will further improve the planning and managing of construction projects. The project file made in the thesis show how to collect all the information in one model, and to take advantage of the data. This includes using the data to visualise the construction process with video animation.

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Abbreviations

LPS - Last Planner System®

BIM - Building Information Modelling

VDC - Virtual Design and Construction

PPC - Plan Percent Complete

AEC - Architects, Engineers and Contractors

IGLC - International Group of Lean Construction

NMBU - Norwegian University of Life Sciences

NTNU - Norwegian University of Science and Technology

LBMS - Location Based Management System
HSE - Health, Safety and En

1 Introductionuctionuction

This chapter explains the background, defines the problem and clarifies the scope of the thesis. The last section shows the structure of the document.

1.1 Background

Research done by SSB (Statistics Norway) shows that the industry in Norway have had a 30 percent increase in productivity. While the construction industry, in the same period, has fallen with 10 percent [1]. Figure 1 shows the development in productivity for the construction industry compared to the other industries on mainland Norway.

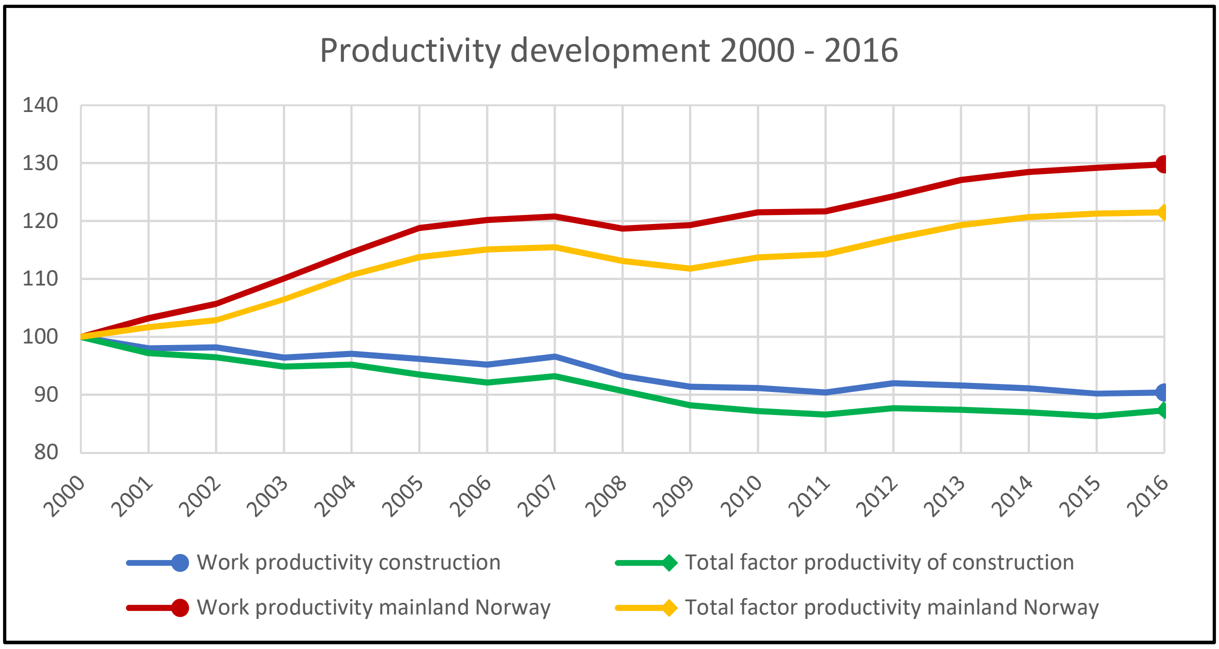

Figure 1 Productivity development 2000 - 2016. Index 2000 = 100 [1]

The Norwegian government came out with a white paper in 2015, where the production growth in the mainland economics in Norway was investigated [2]. The report studied the construction industry, because development in the rate of productivity has been low for the last two decades. This paper suggests that the reason for the low productivity growth in this sector was due to the lack of innovation and commitment to research in the industry.

There is a lot of new technology available, but the industry still uses a more traditional approach. A global research done by KPMG shows that 93 percent of the participants believe that information technology will change the construction industry [3]. The study indicates that the industry knows of the need to use technology in order to improve their productivity.

IGLC 22 was a conference held in Oslo in 2014. The conference main target was to gather researchers and practitioners to present knowledge and experiences about Lean construction [4]. One of the participants was Frode Drevland, who lectures about Lean at NTNU, expressed at the conference the following quote.

> *" Det er veldig mye både tid og penger å spare på å følge Lean-logikken. Kanskje spesielt i byggenæringen. Konseptet er enkelt, det går ut på å organisere prosjektet godt, og å gjøre alt i riktig rekkefølge så man slipper unna unødvendig flytting av materialer og unødvendig ventetid for arbeiderne."* *- Frode Drevland (Original) [5]*

> *" It is possible to save time and cost by complying with the Lean-logic. Perhaps especially in the construction industry. The concept is simple, it is about organizing the project well, and doing everything in the right order to avoid unnecessary movement of materials and unnecessary waiting time for the workforce."* *- Frode Drevland (Authors translation)*

In order to improve the productivity in the construction industry the industry must change. The traditional way might not be efficient enough in the future. Lean has proven to be a method that increase productivity and decrease the need for storage in other industries [6].

1.2 Problem definition

After talking with project leaders in some of the Norwegian construction companies, the author found that there is a lot of talk about Lean, and a spoken interest to use and utilize the methods. However, in construction work done and ongoing project there are few signs of implementation of these systems, and the effort of improvement in practise seems to be missing. Construction companies seems to know that Lean construction is a cleaver solution to help reduce waste and to improve productivity. Nevertheless, the companies still have trouble understanding how to implement the tools and how to utilize them in their projects.

To understand how Lean is used in the construction industry it is necessary to see how far the industry have come, find if there are obstacles and or significant thresholds, and point to where the next steps might be.

The thesis problem definition is:

"To what extent and how has Backe Rogaland AS implemented Lean and Last Planner System in their project and what changes can be made by Lean methods to improve their project planning in the future."

Backe Rogaland AS was chosen for this thesis, because they have used Lean in some projects and are familiar with the Lean theory. The first project where Backe Rogaland AS used Lean thinking was construction work at Radisson Blue Atlantic hotel, which stood finished in November 2017 [7]. Backe Rogaland AS have tried to use Lean in all their projects since. As Lean is an improvement method, it is always something that can improve.

1.3 Limitations

The master thesis is in itself a project. It started in January and is to be completed in June.2019. Within the time limit given it is not possible to follow the project in Backe Rogaland AS from start to finish. The thesis will investigate how the project is planned, and how Backe Rogaland AS plan the future of the project.

The thesis concentrates on the planning process of a project. Therefore, further details concerning the construction site will not be considered.

1.4 Lean

In this thesis Lean is referred to as:

Lean thinking	The philosophy behind the process.
Lean methods	The general method.
Lean tools	The tools used to implement Lean.

Table 1 Lean references

The three references are used to emphasise the different aspects of Lean. The references are all part of the same theory, called Lean.

1.5 Structure of the thesis

Introduction	Explaines the background, defines the problem and clarifies the scope of the thesis.
Methodology	Explaines which research methods that are used to answer the defined problem
Theory	The history behind Lean and an introduction of what Lean thinking and Last Planner System is and how it is used in the planning process.
Lessons learned	How Lean methods have been implemented in the construction industry according to published master thesis.
Digitel tools	Presents BIM and how BIM relates to Lean and Last Planner System.
Discussion and Conclusion	Summarise and discuss the cases presented. Answer the thesis problem.
Appendix	Article for IEEE conference 2019 and the Excel worksheet made for this thesis.

Table 2 Thesis structure

2 Methodology

The problem defined in the introduction can be answered with different research methods. This chapter will explain which methods that are used, and choices done selecting these.

2.1 Quantitative or qualitative research

Finding the most suitable research method is important, and depending on what is the focus for the research. Research methods are usually categorised into quantitative and qualitative method. Quantitative methods emphasize the use of numerical data in the research and qualitative method search for the results through people's experience [8]. Quantitative research is a good method to use for larger studies with lots of data to analyse, for example a survey with many participants.

For small-scale studies a qualitative research method is more suitable, because the researcher is more involved in the research. Qualitative research focus is to get an overall view of the research. Interviews and case studies are often used for a qualitative research. It is also possible to combine quantitative and qualitative research. A qualitative research can help to understand the results from a quantitative research. On the other hand, the results of a qualitative research can be supported by a quantitative research [9].

A qualitative research method is chosen to answer the thesis problem. Because the subject for this thesis is a small-scale study and the researcher is involved in the project.

2.2 Information gathering

Litterature review	Review published work and literature about the subject.
Survey	Questions are sent to a number of participants. Precise questions are important for the survey in order to gather usefull information.
Case study	Investigation of a project or a few chosen research subjects. The target is to describe and explain the situation.
Interview	Interview with one person or more that have knowledge about the research subject.
Observations	Information data comes from the researchers own observations.
Use of existing data	Evaluation of information from reports.

Table 3 Information gathering methods [9] [10]

Table 3 shows some of the methods used to gather information to answer research questions. Which methods to use depends on what the researcher wants to investigate. Using a combination of methods is called triangulation [9].

Triangulation is used for this report to overcome weaknesses in some of the chosen methods. This thesis will investigate the planning process in one company. Therefore, case study was chosen as the most suitable method. Information data for the case study was gathered from unstructured interviews, non-participant observation and document study. Analyses of projects in Scandinavia has been conducted to understand how other projects have utilized Lean methods. The analyses have been conducted in published master theses. Interview was used as a method to gather information about a current project in Norway.

2.3 Case study

A case study gathers detailed information about one or more cases [11]. The cases can be one person, a group or a company. According to Robert K. Yin a case study investigates the situation in the real-world context [12]. During the case study, the researcher will have a different opinion of the case, than the participant. This is because the researcher have the benefit to see the case from the outside, while the participant is limited by their involvement working on the subject of the case [8]. Empirical data is gathered to understand the case and to develop an understanding of how the company performs.

2.3.1 Interview

An unstructured interview structure was the best solution to get the information data for this case study. The interview method is a personal face-to-face conversation. An unstructured interview is flexible and open for the interviewer to ask supplementary questions, helping the interviewer to get to the depth of the case.

In this thesis the following interview have been conducted:

- Backe Rogaland AS
    - In person on 3rd of May 2019, Stavanger
- Total Betong AS
    - Skype on 3rd of June 2019, Stavanger

2.3.2 Non-participant observation

To understand how the meetings in the planning process worked, the author of this thesis conducted non-participant observations. The author observed the meetings and took notes. A non-participant observation means that the observer does not involve them self in the meeting [11].

2.3.3 Document study

Document study was performed to support the observations. Since the author of this thesis came in after the project planning had started, a document study was done to understand a larger part of the planning process in the company.

2.3.4 Excel

An Excel work sheet was produced as a product of the thesis to suggest how the company may improve their planning process. The work sheet presented here is aimed to help a project team to structure the information to the subcontractors. In this study the worksheet is aimed as a proposition to the Ledaal Park project of Backe Rogaland AS. The interactions inside the Excel worksheet will reduce time and help the project team during the planning of a project. The worksheet is explained in section 6.3.

2.4 Literature review

A literature review was done to understand Lean. The author has read the history behind Lean, Lean production and Lean in construction. To understand the theory the author has found different sources that present the Lean tools, the methods and systems of thought. Based on the literature review the author has written chapter 3 Theory.

2.5 Survey

During the initial stage of the thesis, a survey was considered to gather the status of Lean in the construction industry in Norway. Doing such a survey was later dismissed. The reason being that there already exits such surveys in surplus. An examination of previous master's thesis, concerning use of Lean in the construction industry, shows that a great deal of them had performed a survey. An additional survey seems superfluous. Making one would not contribute to the research on the topic.

3 Theory

This chapter gives an introduction of what Lean thinking and Last Planner System is, and how the theory and system are used in the planning process. Firstly, the history that lead the way to Lean and Last Planner System. Secondly, a description of the many Lean and Last Planner System tools that are applicable in a project.

3.1 History lead the way to Lean thinking

In 1881, the American engineer and inventor Frederick Winslow Taylor started to study time used in each step of the production line. He then divided jobs to structure them into measurable elements [13]. The changes standardised the work and made the workflow easier. It also made the work more efficient and manageable. Frederick Taylor called the theory for "scientific management" [14]. The theory is that the workers should work with minimum effort and be used efficiently. This is perhaps the starting point to Lean thinking.

Henry Ford found a way to reduce costs and increase product quality at the same time. His work with standardisation started in 1906. Ford started making cars that had standardized connections, meaning all connections were similar on every car. The standardisation shortened the assembly time. When the same mechanic does the same work repeatedly, the duration of each task is shortened [15]. Ford figured out that moving people from one station to the next took more time than moving the products. Moving the products instead of people helped create flow in the production. All changes helped to reduce waste and to increase value. Henry Ford called this method production for "mass production".

Both Frederick Taylor and Henry Ford had problems with their management systems. The Scientific management does not take the element of human development into considerations. Human development means how humans need change and a feeling of development. The tasks in both management systems were very monotonically for the workforce. People do not like to do the same work repeatedly, like a machine. This management style was very controlled and did not allow for any changes suggested by the workers. Moreover, Henry Ford's production style did not take customers' demands in to account. Customers wanted the products to have different colours and styles. Ford did not offer any variations for the customers, because of the expenses it takes to change the production systems. Lack of demand led to overproduction, which is a major flaw. Overproduction is a huge waste of resources.

In 1950, William Edwards Deming was invited to Japan to lecture management. The issue was how to decrease costs and at the same time increase quality [16].. William did not believe the management saw the connection between improving quality and staying in business, see Figure 2. He made the management understand that improving quality was good for the company. The lack of quality in the production made it necessary to have many people correcting the defects. Instead of correcting defects, the company should find out why the defects occurred and make sure the defects never happened, in the first place. This led to production of better-quality products and less defects in the production line. By doing it correctly the first time the company would save the cost of more labour hours to correct a defect. For W.E. Deming it was important that people worked smart, rather than hard.

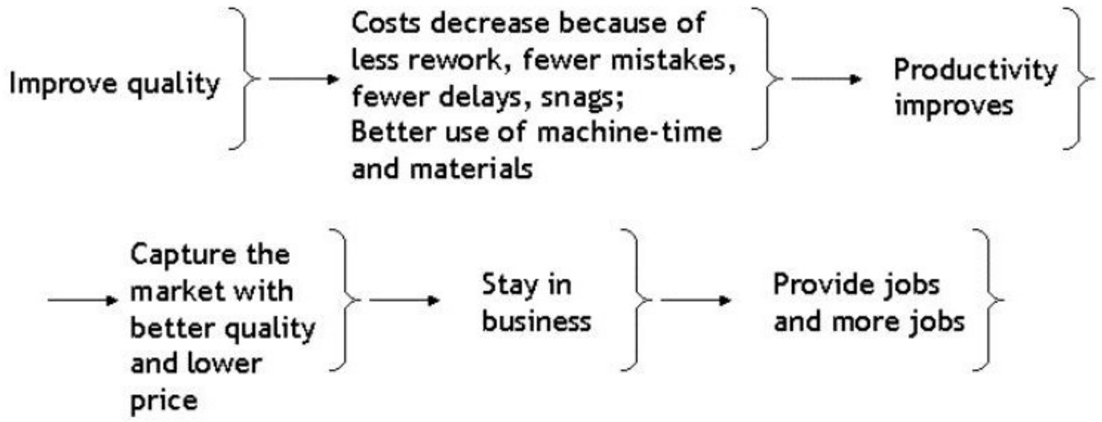

Figure 2 Chain reaction [16]

From Deming's studies of management and his theory of continuous improvement, he came up with the idea of a Plan-Do-Check-Act cycle (Figure 3). First plan and design a product, then develop it. Afterwards the product is checked if the consumers buy it, act on what the consumer thinks about the product, and find out what could be improved. When the processes are done, the cycle starts again to improve the product further.

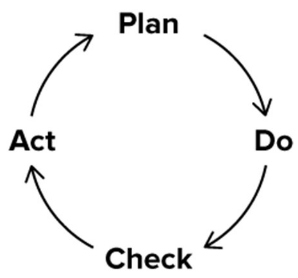

Figure 3 Continuous improvement [16]

Production styles have changed over the years, as seen in this chapter. Management theory has changed from time measuring exercises to explaining how managing mass production can improve quality. This has all led to new ways of thinking on how a production line works. Eiji Toyoda, an engineer from the Toyota production, visited the Ford production line. Eiji Toyoda understood that the Toyota production could not mass-produce the same way as Ford, because the Toyota production did not have the resources or capacity [17]. With the help from Taiichi Ohno, Toyota production figured out they needed another production system to challenge the market. The Toyota production could produce in less quantities and change the machinery settings faster to produce a diverse product.

The Toyota production figured out that by finding the cause of the defects, and make sure defects did not happen again, the production saved time and reduced waste. This also led to improved quality, because all products that was finished, had zero defects. Storage space was saved since the products were made based on customers' demands. This is the start of Lean production. Taiichi Ohno is the man behind the theories known as "just in time", the "five why's" and the "seven wastes" which is a big part of Lean thinking and will be explained later.

3.2 Lean construction

Lean thinking started in the Toyota production factory. Toyota found an easier and faster way of mass-producing vehicles. Focusing on the sources of waste and flow, and to continuously improve Toyotas product. Problems were uncovered early in the production system, therefore there were never any defects when the product was complete. Over the years, many companies have adopted Lean thinking to their production. Lean thinking in production is mostly referred to as Lean production.

Lean construction referrers to how the Lean methods can be used in the construction industry. In Norway, a few companies have started implementing Lean into their projects. In construction, Lean thinking can help discover the source of wasted resources as human potential, material waste and time. The sources can be detected by using different Lean approaches as pull planning, just-in-time principals and daily coordination meetings to name a few. Frequent meetings between workers decrease misunderstandings and problems can be solved faster and decrease delays. The Lean principles is explained underneath.

The seven waste [18] [19]:

1.	Overproduction	Completing more work before it is needed.
2.	Inventory	Raw material, work in progress or finished goods which is not having value added to it.
3.	Waiting	People or parts that wait for the next step in the process.
4.	Unnecessary motion	Unnecessary movement of people, parts or machines between processes.
5.	Transport	Unnecessary movement of materials.
6.	Over-processing	Doing more than needed by the customer.
7.	Defects	Rework and correction of a process.

Sometimes a last waste is added:

8.	Under-utilized talent	Not seeing the full potential of the workers talent.

Five why's:

Taiichi Ohno found out that asking "why" five times helped to discover the real cause of the problem. Using this method, the Toyota production found the underlying cause of problems. Having the cause, the Toyota production could find out how to challenge and solve the problem. Before the production had only fixed on the problem visible and did not investigate why the initial problem occurred. When a machine breaks down there is usually a cause, but what is the reason leading to the first cause. Asking "why?" helped the workers to fix the underlying problem. Sometimes asking "why" even more than five times is needed [20].

A3 sheet:

From Deming's Plan – Do – Check – Act theory Toyota Production have made a A3 Sheet. The A3 sheet is in fact a A3 sheet of paper with different sections. The sections depend on what is relevant for the project and who will use it. A typical construction sheet will be explained underneath [21].

1. Background
2. Current conditions
3. Goals/Targets
4. Analysis
5. Proposed countermeasures
6. Plan
7. Follow up

These sections help to figure out the problem, why the problem occur, the target and actions that can be taken to solve the problem. When filling out this sheet it is important to use the five why's to discover the real cause. The paper also contains a title, a champion and a timeline.

The 5 S:

The 5 S helps keep the work environment clean and tidy. The system is a guide to improve and keep a good work environment [21].

- Sort — Divide items into needed and unneeded. Eliminate the unneeded.
- Straighten — Have needed items in assigned place for easy and immediate retrieval.
- Shine — Keep work area clean and tidy.
- Standardize — Make a system to keep the work area "sorted", "straightened" and "shine".
- Sustain — Maintain the procedures.

3.3 Last Planner® System

Last Planner System (LPS) is a planning, monitoring and control system that follows Lean construction principles [22]. The last planner is the person responsible for the work done in one section of the production, this could be the person responsible for the electrical system. Glenn Ballard first introduced the system in 1993. Glenn Ballard is one of the leading researchers on Last Planner System and a founding member of the International Group of Lean Construction (IGLC) [23]. IGLC is an international network that wants to change the production management concepts in construction industry.

In Last Planner System, the plan is more detailed closer to the execution of the task. In the start of a project, there is a Master plan with few specific details. At the start of every week, a detailed plan for every task is made.

Last Planner System has four mechanism. The mechanisms are what should be done, what can be done, what will be done and what did get done. These mechanisms helps the project leader look at the flow of the project. The mechanisms are a guide for the Last Planner System. *Should* is making the plans for the project to be successful. *Can* is focused on ensuring that the work can be done. *Will* is what each last planner will do to fulfil the promises made in phase planning. *Did* is how the project was and what can be learned and improved in the next project.

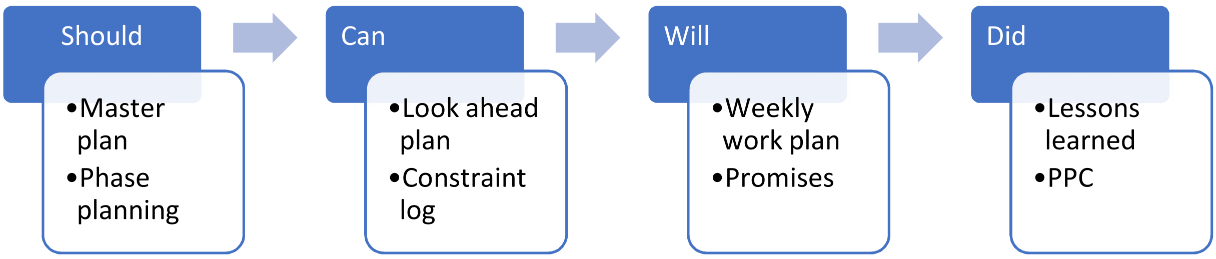

Figure 4 Last Planner System mechanism

3.3.1 Master plan

The master plan consists of milestones. The milestones are the start and finished dates and other important milestones for the specific project. The project leader usually sets up the milestones. The milestones are set to help give projects a strategy and stability [24].

Each milestone is a goal for the project and the tasks that are set to be done by the given date. This will help the project to finish on time. The master plan should be updated when subcontractors are selected for the project, to be up to date.

3.3.2 Phase planning

In phase planning it is important to find a good float in the project. The phase planning is preformed to find which tasks of the project that can be considered as a unit, and to specify the hand-offs. The units in phase planning are in-between milestones set in the master plan. A hand-off is where one person release an activity so the next person can take over. It is also important to identify conflicts of operations where constraints might occur.

Phase planning is done in meetings with the subcontractors. The worker gets more ownership over the project by being involved in the planning. Sticky-notes are used to make the plan. The participants discuss the best task sequence and how the work should be performed in the meetings [24].

Pull planning is used in the planning process and will be explained below in section 3.5.

3.3.3 Look ahead plan

A look ahead plan contains the work that are planned for 2 or more weeks ahead. The look ahead plan for 1 week ahead is often called a “make ready plan” or a “weekly work plan”. Both plans focus on finding constraints and clearing obstacles. Therefore, only healthy tasks will be allowed to start. A task is healthy when there are no constraints stopping the task from being processed. Some of the most known constraints are:

- Information
- Material
- Crew
- Equipment

- Space
- External conditions
- Previous tasks

When something interferes with a planned task it is called a constraint. All constraints in a project is written down in *a constraint log*. This log contains a description of the interference, actions taken to resolve it, the responsible person and the date when the problem should be resolved.

By making a "make ready plan" the last planner looks ahead and find out which tasks need to be ready. The plan is to ensure that any constrains is resolved before the task is set to start.

A look ahead plan for six weeks will show the next six weeks of the project. The plan helps the project team to investigate what is important to order and to be delivered, ensuring the task is ready to start on time.

Look ahead planning is important to discover constraints and to resolve them before a constraint affect the project. Each company makes a look ahead plan with the tasks their team can do the following week.

Constraints should be recorded in a log. The constraints log help to make it easier to keep track of the problems that occur in the project. The log can later help the project team learning from their mistakes and improving their future projects.

3.3.4 Control and lessons learned

There is weekly coordination between the project team and the responsible persons from each company involved. The meetings are often stand-up. The aim of these meetings are for the participants to talk about what is set to be completed and what is accomplished. Furthermore, to agree if changes must be made in order to finish.

PPC:

Plan percent complete (PPC) measures the progress of the plan. PPC is calculated by dividing number of assignments completed on the day stated, on the total numbers of assignments made for the week [25].

$$\text{PPC} = \frac{\text{Number of assignments completed on the day stated}}{\text{Total numbers of assignments made for the week}} \times 100$$

The calculated answer says something about the progress of the project according to the plan. Before implementing Lean methods, the PPC calculated is typically around 50 percent, where a 100 percent is a perfect PPC [25]. The PPC can be calculated at any time throughout the project assuming the proper information is obtained. In such a fashion the PPC will monitor and show the progress of the project. PPC helps the project team to control that the tasks are done when the subcontractors promised.

Lessons learned:

It is important to learn from every project and improve the technics for the next project. Writing a report on how the project proceeded can be gathered. It can be used to avoid making similar mistakes in the next project. Improving for every project will increase the quality and enhance productivity in future projects.

Figure 5 shows the input and output of the Last Planner process.

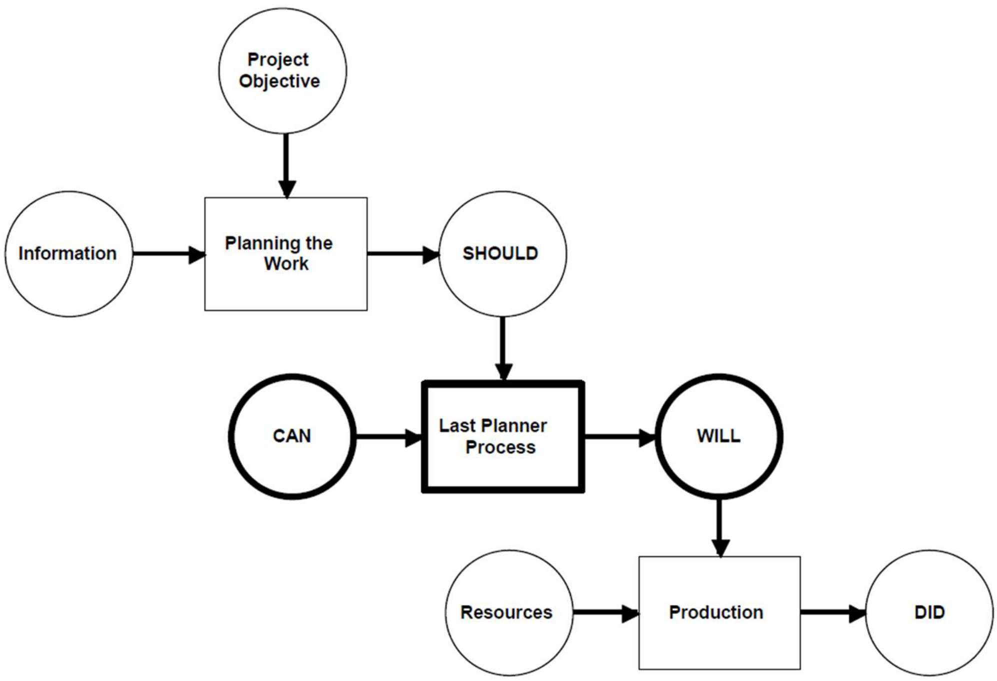

Figure 5 G. Ballard Last Planner System [25]

Functions of the Last Planner System is [26]:

- Specifying who and when a task should be done
- Having scheduled tasks ready to be executed
- Planning and reschedule tasks to complete project
- Making daily and weekly work plans
- Coordinating hand-offs
- Visualize the current and future state of the project
- Measuring plan percent complete (PPC)
- Learning from past mistakes

3.4 Push planning

In productions systems push systems are often used. The meaning of push planning is that each step in the process produces what the process management believes the next step in the process will need. Then the plan will push the product through the production line [20]. If the system produces more than in demand, the product must be stored. In the construction industry push planning is the traditional way of managing projects. The project manager plans the project and calculate the time for each step. The planning is made without consulting with the people doing the work. After planning, the project manager pushes the project through. Usually problems and delays happen in the process of carrying through the project. The workers don't communicate the problems, and new problems occur. Figure 6 shows the inputs and outputs in a push system.

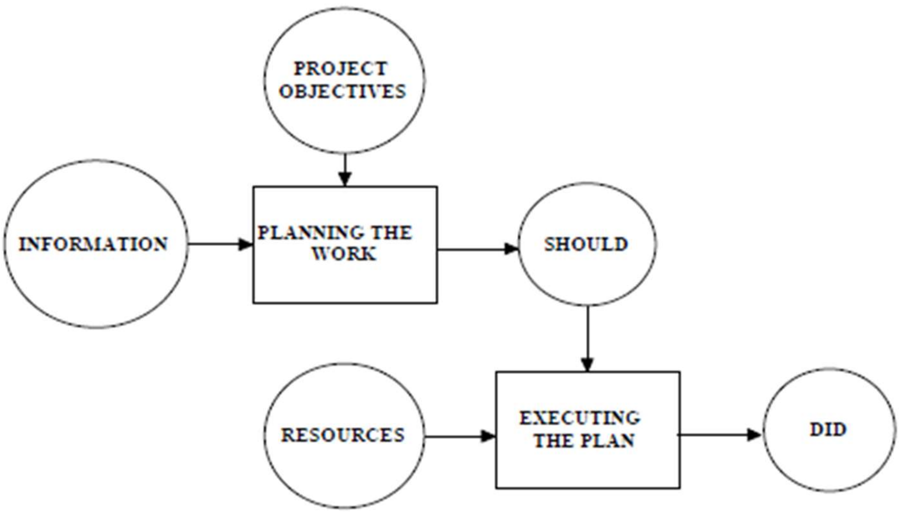

Figure 6 Push planning system [25]

3.5 Pull planning

Pull planning is the opposite of push planning. In pull systems, the productions is regulated by customer demand. Taiichi Ohno came up with the idea after hearing about supermarkets in the USA. In supermarkets customers picks the items the customer needs at the time. The store will only restock the items that are in high demand by the customers. If a product is less attractive for the customer, the store will order less or stop selling the product. The customer will only buy what they need. This way the supermarkets don't buy unnecessary goods and less waste is produced. This supermarket system is called a Kanban. Kanban is the idea behind pull planning.

When a factory starts implementing a pull system, the system will soon crash due to many complications. Nonetheless, the system crash means that the system is working. That is because it shows all the flaws in the system that was in place [20]. When mistakes happen, it is not due to a flaw in the system. It is because the system is working and showing where the mistakes are. Here the production finds out what the systems needs to work on. The second attempt will probably last longer than the first and will show new problems. After solving the new problems, the factory should repeat this cycle until there is a flow in the system. Pull planning is a scheduling system set to reveal problems [20].

In construction, pull planning is done by the project manager. The project manager will be asking the contractors how long time the contractors will use on one task and which task must be done before the contractor's work can start. For example, an electrician might need that the carpenter is done with a specific task, before the electrician can begin their task. By asking the worker, the plan becomes more realistic and it is more likely to stay within schedule. See Figure 7 for the inputs and outputs in a pull system.

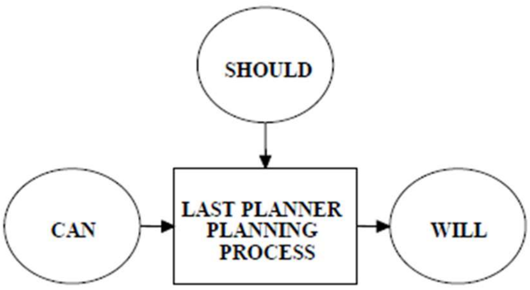

Figure 7 Pull planning system [25]

3.6 Poka yoke

“Poka yoke” means “mistake-proofing”. A process designed to prevent human errors. Dr. Shingo came up with the practice to minimize defects that came from human errors [27]. If the mistake is detected before the product is finished, the mistake will not be classified as a defect. Mistake-proofing can be done in many ways. For example, a mechanic can pick out all the bolts to be used in a product into a separated box. When the product is assembled the mechanic should have no bolts left in the box. If the box is not empty the mechanic knows the product are missing some bolts and can discover the mistake before the product moves along the production line.

On a construction site one tool of the mistake-proofing is done by using BIM. Building Information Modelling (BIM) will be explained in section 5.1 . BIM can as an example, show where ventilation systems and sprinkler system have focal points. If there is too little room for the systems and there is need for more space for the focal points, the constructor will see the problem in the planning stage of a project., The planning tool will make it is easier to fix.

3.7 Just in time

The principle of “just-in-time” is supplying "what is needed, when it is needed, and in the amount needed" [28]. Reducing the need for storage. Having a long-term agreement with a supplier will make it work. Companies that use the “just-in-time” principle, have fewer suppliers. The suppliers the companies engage, are viewed as co-partners in the production [20]. In the production a kanban system is often used. The Kanban system signals a need for action. Kanban is explained in section 3.5.

3.8 Takt time in construction

Takt time is a way to get workflow. It can be referred to as finding the proper rhythm of a specific work to get the right flow [20]. To illustrate Takt time, the movement of wagons in a train is a popular image. The train moves from zone to zone as the construction progress. A zone can be one room, a floor or a section of the building. The train have multiple wagons where, in this illustration, each wagon is a trade. The Takt time is how long one wagon will be in one zone before moving to a new zone. Since the train moves at the same speed, the trades must move to the next zone at the same time.

The first wagon on the train is the carpenter, second is the electrician and third is the plumber. If the Takt time is set to 3 days a carpenter will start in zone A. After 3 days the carpenter must move to zone B so that the electrician can start to work in zone A. Next 3 days the carpenter moves to zone C and the electrician accordingly move to zone B, making way to the next trade, the plumber, to start work in zone A.

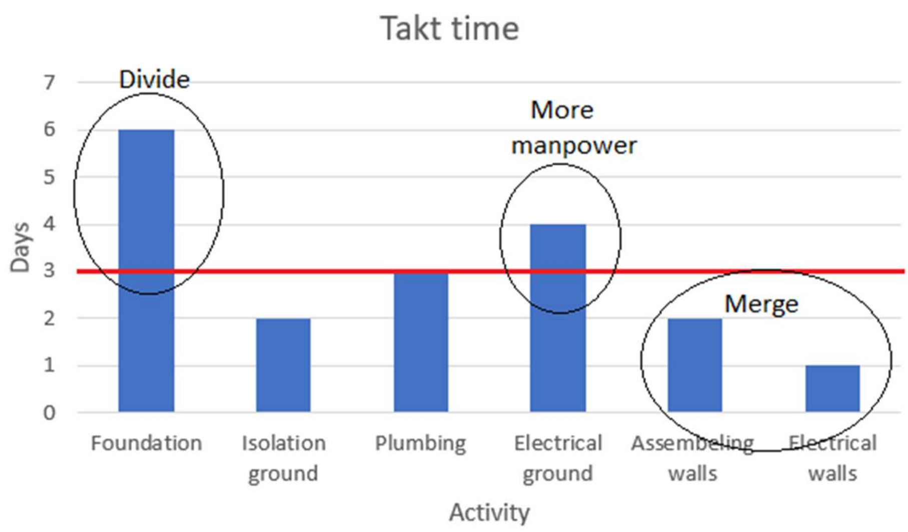

Figure 8 Example of Takt time

To establish the Takt time for the project all trades define their activity and work hours for each zone. A bar chart is used to compare the time each activity needs (see Figure 8). The x-axis shows the activities and the y-axis shows the number of work hours. The average amount of days is usually used as the Takt time. For works, that needs more time than the Takt time can be divided into several tasks or given more manpower. A divided task will then have two wagons after each other instead of just one in the illustration used of a train. Similarly, smaller tasks can be merged together in one Takt, or share one wagon using the train example.

3.9 Pareto Chart

A Pareto chart shows which constraint occur the highest number of times in a defined time period [29]. Figure 9 shows an example of a Pareto chart. The information of reasons is usually collected from the constraint log. A Pareto chart highlights the constraints that occurs the most during a project. The reason for constraint that occurs most often is first and the cause that seldom happens is at the end of the chart. When a cause for a problem is high the Pareto chart will highlight the problem. The chart makes it easier to discover where the real cause of the problem is. This way the most influencing constraints are found, and action can eliminate the problem.

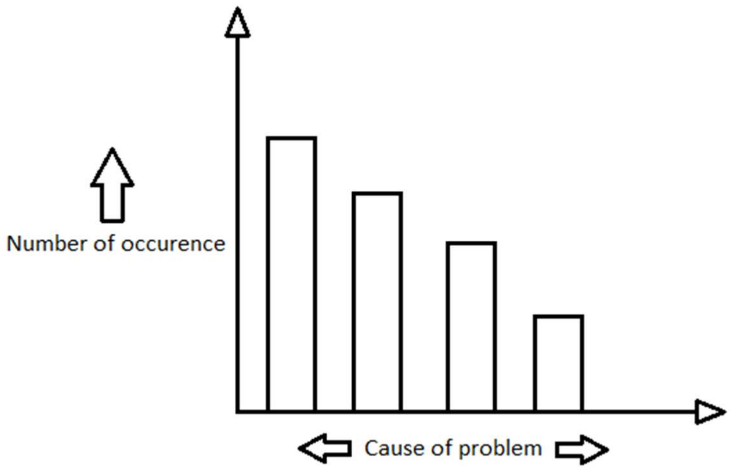

Figure 9 Example of a Pareto chart

4 Use of Lean and Last Planner System® in Scandinavia

This chapter will investigate published master thesis and an interview to see how Lean construction has been implemented into construction projects. The chapter indicates to what extent Lean construction methods are implemented in Scandinavian companies and their projects.

Several theses have conducted interviews and surveys on how Lean construction and Last Planner System can be used to improve the construction industry. In these studies, many companies state that Lean construction is in use. While researching to this thesis, such statements seem not to be entirely correct. After having talked to some companies, it appears that Lean construction and Last Planner System is still a new concept to most of the professionals in the industry.

The author of this thesis investigated two previous master theses that contains case studies of three construction projects. Furthermore, an interview of a nearly finished project was also researched for this thesis. The projects are investigated for their use of Lean methods.

The investigation of the cases concentrates on the use of Lean and Last Planner tools that are explained in chapter 3, and listed underneath with references to the section were the explanation is:

- Master plan 3.3.1
- Phase plan 3.3.2
  - Push planning 3.4
  - Pull planning 3.5
- Meetings 3.3.2
- Look ahead plan 3.3.3
- Constraint log 3.3.3
- Takt time 3.8
- PPC 3.3.4
- Lessons learned 3.3.4

Table 4 contains a description about the projects investigated.

Frederikskaj

- Contractor: MT Højgaard A/S
- Copenhagen, Denmark
- Total gross area
- Building periode: 2016/2017
- 3 new apartmenst building

Musikhus Kvarteret

- Contractor: A. Engaard A/S
- Aalborg, Denmark
- Total gross area 14 500 m^2
- Building periode: 2014-2016
- 7 new apartments building

Urbygningen, NMBU

- Contractor: Statsbygg and Ministry of Education and Research
- Ås, Norway
- Contract value: 470 millions NOK
- Total gross area: 8190 m^2
- Building periode: 2013-2017
- Rehabilitation of old university building

Sjøtroll

- Contractor: Total Betong AS
- Bryne, Norway
- Contract value: 650 millions NOK
- Total gross area 14 000 m^2
- Building periode: 2017-2019
- Land-based fish hatchery

Table 4 Case information [30] [31] [32] [33]

4.1 Projects in Denmark

At Aalborg University, three master students have written a master thesis about Last Planner Systems. The title is “Successful application of Last Planner System combined with Location Based Management System” [34]. All information given in section 4.1 is from reference [34] if nothing else is mentioned. Location based management system (LBMS) is a new way to plan and manage a project. The system increases productivity, efficiency and speed while integrating the critical path. The focus for investigation in the cases will be Lean and Last planner. LBMS will not be explained any further.

The master thesis conducts two case studies. The main target of the thesis was to research how the project manager put Last Planner Systems into use and which of the tools the companies utilized. In both studies, the construction work was apartment buildings in Denmark. The first case concerns the company MT Højgaard A/S. MT Højgaard A/S is one of Denmark’s main contractors, with a turnover of 6,8 bn. DKK in 2018 and 3 900 employees [30]. MT Højgaard A/S has developed TrimBuild, which is a process management concept built on the principal of Lean construction [35]. Frederikskaj is the project from MT Højgaard A/S.

The second case concerns the company A. Enggaard A/S, as both the owner and the developer. A. Enggaard A/S is a family owned company, and a smaller firm than MT Højgaard A/S. The turnover in A. Enggaard A/S is 2,2 bn. DKK in 2018 with a workforce of 344 [36]. Musikhus Kvarteret is developed by A. Enggaard A/S.

In the following case studies, “the students” refers to the master students that wrote the original report on the construction projects. Problems and proposed solutions from the report will be presented in the following.

4.1.1 Frederikskaj

The first master plan was prepared during the project proposal two years before the construction work started. It was redrawn closer to the start of the building period by the project manager. The leader of every trade committed themselves to the schedule with signatures.

Phase planning was used as the agenda in the meetings with workers and contractors. The plan was used to anticipate the progress of the construction, and the requirements for activities ahead. Pull planning was not conducted since the project was performed using Location based management system. LBMS gave the project a detailed schedule from the beginning of the building period.

MT Højgaard A/S starts their projects with a kick-off meeting. At the kick-off everyone involved in the project is present. That includes managers, contractors, clients and advisors. The project manager leads the meeting. The concept of TrimBuild is introduced so everyone at the meeting are familiar with it. An anonymous stress barometer is introduced as a tool to monitor the stress at the workplace.

Look ahead plan was taken out from the LBMS and applied for 5 weeks. The plan was discussed at a weekly meeting. Weekly work plan meeting was held every Tuesday, one for leaders of the trades and one for contractors. In the meetings, the participants discussed the plans for two weeks ahead. So, every week was planned twice, this increased the plans accuracy. Concrete workers had their one weekly work plan following agreements from the weekly meetings. All requirements for the activities in the 5 weeks look ahead plan were discussed at the weekly meeting.

Workable backlog was considered. A Workable backlog is like a make ready plan with only the healthy task. However, the workable backlog was considered time-consuming and therefore not used. In this project the project manager used an obstacle list which resembles a constraint log. The obstacle list showed the problems at the site, who was responsible and when the problem would be solved. Takt time was not used.

Plan percent complete (PPC) was not introduced into the project, because of the time it takes to gather all the information. The project manager considered the information gathered from workers not to be accurate. The reason is that workers will answer roughly, rather than accurate. Instead the project manager used a simplified method. The simplified method focused on which stage each task was in. There were a variation of stages a task could be in. The stages were: Not started, in progress, completed, running late or a variation of these. The simplified method of PPC reduced the time of gathering data and helped to emphasised productivity of the project at the weekly meetings. The project report was kept well-documented because of the simplified PPC recordings.

In addition, the project only had a buffer zone at the end of the project. This decision was based on the assumption, that if there where buffer zones in between activities, the workers would not be as productive as if the buffer was at the end of the project. Having no buffer zones made tight deadlines and resulted in a stress-full workplace. Subcontractors were under pressure to keep task on track. The master students proposed that using Last planner tools could improve communication. The report also suggests making the contractors focus on the joint benefits of communication between contractors and subcontractors.

To conclude, the case study uses some of the important aspects in Last Planner System, namely the master schedule, phase planning, look ahead plan and weekly meetings. The project in the case also use a Location based management system to replace some of the tools from Last planner, like pull planning. It is not mentioned in the report what other Lean concepts the Frederikskaj project use.

4.1.2 Musikhus Kvarteret

In this case the master schedule was very simplified. The master plan was not changed since the start of the project. According to section 3.3, when the project develops, the plans should get more detailed. The project at Musikhus Kvarteret did not add information to the master plan as the project developed and subcontractors got involved.

Phase plan is done in the traditional way, meaning that push planning was used. Push planning is explained in chapter 3.4. The plan is made with all the subcontractors present and in conversation in a meeting. In weekly work meetings a detailed plan is produced in collaboration between the contractors and the developers. The meetings included a status update of the project and planning the following week. In addition, the project has a work environment meeting every second week. The work environment meeting is a safety inspection of the project site, to ensure the work is performed in a safe manner.

Look ahead planning was difficult in the project because customers had the opportunity to customized and make changes to the apartments. Therefore, the project manager chose to only plan for the next week.

The students stated in their report that problems that occurred during construction was seldom analysed to find the cause. By using the “5 whys” tool the cause of the problem could have been detected and solved, and may be eliminated in the project. The project had some trouble with delivering of materials due to misunderstandings that caused delays. The delays could have been avoided with better communication with a work ready plan according to the students.

To summarize, this project management does not implement Last Planner System properly in the Musikhus Kvarteret project. The master plan is not updated after subcontractors are involved. Phase planning is conducted in a more traditional way, with push. The project suffered delays because of misunderstandings that could have been avoided with better communication and a make ready plan. A look ahead plan was not introduced in the project, though they used a one-week plan. In many ways the project was run in more of a traditional way.

The subcontractors were chosen based on two main factors, the lowest price and if the subcontractor company had worked for the contractors earlier on. The case shows a high level of trust between management and subcontractors because of earlier dealings and experience.

The report concludes that some of the Last Planner System concepts are complicated and some are looked at as unrealistic to follow. The system creates more confusion in A. Enggaard A/S project than improvements. The students suggest that there might be simpler way to improve a project for A. Enggaard A/S than using time-consuming concepts like PPC and make ready plan.

4.1.3 Summary

For improving construction projects, the students propose some changes:

- Proposed change to the master plan is to rewrite the schedule when subcontractors gets involved in the project. In this adaption the information about the project is updated.
- Having a kick-off meeting. The purpose of the meeting is to develop teamwork, assign responsibility and help the team bond.
- Look ahead plan could have been performed if the developer did not allow for changes when the building process had started.
- Produce a make ready process. To help the trades prepare activities to be ready when the activity is planned. Find out if everything is ready for the execution of the activity.

- Preform a simpler PPC. Where contractors report the present the activity percentage complete.
- More detailed tracking of variances. Report problems in a Pareto Chart to discover the most common problems.

4.2 Projects in Norway

The master student, Kåre J. Haarr has written a master thesis explaining the use of Lean construction in Statsbygg. The thesis contains a case study of Statsbygg rehabilitation project of a university building at Norwegian University of Life Sciences (NMBU). The thesis title is "Lean Construction i Statsbygg – Casestudie av et rehabiliteringsprosjekt" [32]. All information given in section 4.2 is from reference [32] if nothing else is referred to. Statsbygg is the Norwegian government's key advisor in construction. The annual report for Statsbygg from 2018 set the revenue at 7,9 bn. NOK and 929 people in the workforce [37]. Statsbygg is the main contractor for the construction of "Urbygningen".

Total Betong AS is the contractor for one of the world's largest land-based fish hatchery, named Sjøtroll. Information in section 4.2.2 is from an interview with two informants from Total Betong AS if nothing else is referenced. Total Betong AS annual report reports the revenue for 2017 was 260 mill. NOK and the workforce consists of 81 employees [38].

4.2.1 Urbygningen

Urbygningen is an old university building at NMBU at Ås, Norway. The building was completed in year 1900. The gross area of the project is 8190 m^2. Urbygningen is preserved by the Norwegian Directorate for Cultural Heritage, because of the historically significance of the building. The building is being rehabilitated to satisfy the necessary requirements for today's lecture facilities.

Statsbygg was determined on using Lean theories in the project. In the bidding process, Statsbygg required all the participants to go through a Lean certification called Lean six sigma. The course explains the methods used in Lean (see section 3.2). The certification can be taken at three levels, Statsbygg required the lowest level. Because of the Lean course requirement everyone involved in the project had some understanding of the theories connected to Lean.

It is unclear from the report how the master plan was created. According to the report, a feasibility study was conducted twice for the project. By whom is not mentioned. The feasibility study was done twice because the project did not get the necessary political approval in the first round of proceedings.

Phase planning was done with collaboration meetings between the contractor and the subcontractors, 4 meetings in total. The meetings were set 3 months before the building process started. Knowledge transfer and a progress plan was on the agenda for the meetings. Judging from the participants feedback, the goals for these preamble meetings were not clear. The lack of clarification made the meetings less useful and the participants could not take full advantage of them.

Statsbygg scheduled for several meetings, using a 14-10-8-4-1 weeks meeting structure in the beginning of the project. During the project, the schedule was changed to a 4-1 weeks meeting structure. The meeting structure was changed, because after the meetings unexpected problems occurred. New solutions had to be discussed in a new meeting, losing the meaning behind of the earlier meeting, according to Kåre Haarr’s informant.

The 8-week meeting was a look ahead meeting. In the beginning the project arranged for a pull system. From the interviews, Kåre Haarr got different reasons for why pull planning failed. One reason was that the participants in the project did not have enough knowledge of pull planning and were not prepared for the meetings that was set. The project team brought in an external consultant to help. When the external consultant came into the project, key people lost ownership over their work. This might be the other reason for why pull planning failed.

Takt time was used in the project. But since there were many unforeseen difficulties the Takt time failed as well. There was not enough buffer room for problems that was hard to predict. This resulted in delays and key personnel lost trust in the Takt time. Halfway through the project Takt time was terminated and traditional planning took over.

The informants had different opinions if a rehabilitation project was ideal for Last Planner System planning or not. There are a lot of unknowns and many variables when rehabilitating a building. An informant said that the unknown was what made pull planning difficult, because of all the changes that had to be made during the project. While other informants said that it would be harder without pull planning, since the project started to look ahead early and could therefore remove problems before work drawings were produced. Because of the problems described the project started using a traditional weekly plan.

Building Information Model (BIM) was actively used throughout the project. BIM is explained further in chapter 5. There were BIM stations in the building were the workers could get updated information and details. The stations were well used. Feedback shows that the workers would like the BIM model to be higher up in the contract hierarchy to include more details. That way the workers could depend more on the details given in the BIM model to be correct.

Haarr's report focuses on what Statsbygg has done to implement Lean to the project. He has gathered information and thoughts from the participants in the project. No suggestions for improvements are given. Kåre Haarr's conclusion is that the project failed to implement Lean construction and Last Planner System.

The main reasons he found are:

- Failed to establish a Lean culture in the project
- Participants failed to communicate and work together
- Production system was adjusted to the interest of the entrepreneur and the client
- The Urbygningen project had a high degree of unknown variables

4.2.2 Sjøtroll

Information given in this section is gathered in an interview with two informants on 3rd of June 2019. The informants are part of the project team in the Sjøtroll project. The information is the informant's subjective opinion, and therefore can be biased.

Sjøtroll will become one of the world largest land-based fish hatcheries. When completed the hatcheries will produce 12,5 million fish in a year. The project started in spring 2017 and is set to set to be delivered on schedule in May 2019. The total gross area of the hatchery is 1400 m^2.

The project team started implementing Lean and Last Planner System in the summer of 2018. The project started implementing Lean and Last Planner System in the Sjøtroll project to have more control in the planning process. From the beginning of the construction and until summer 2018 the project had a traditional plan, where the project team pushed the plan through. A external consultant was brought into the project to help the project team in the transition from traditional planning to use Lean and Last Planner System. In the beginning of the transition the consultant was at the project site once a week. However, when the project team understood the Lean method there was less need for the consultant.

The project team made a master plan with milestones in the summer of 2018. The workshop meetings where conducted with a milestone as the agenda. The workshop meetings are similar to phase planning. During the workshop the participants makes the plan to reach the goal of the milestone. Every trade is present at the workshop meetings.

The plan is made using sticky notes. For the plan to be completed the project has two workshop meetings, for two milestones set in the master plan. In addition to workshop meetings, the project has 6 weeks look ahead meetings, weekly meetings and morning meetings 4 days a week. The project team uses 6 weeks look ahead plan. The 6 weeks plan includes the task set for the next 6 weeks. In the weekly meetings the subcontractors plan the task for the following week. During the morning meetings the subcontractor are asked about the status of 5S (see section 3.2) and of health, safety and environment (HSE). The status is recorded on the information board at the project site. The morning meetings is stand-up and lasts around 10 minutes. Figure 10 is a picture from the Information board on the Sjøtroll project.

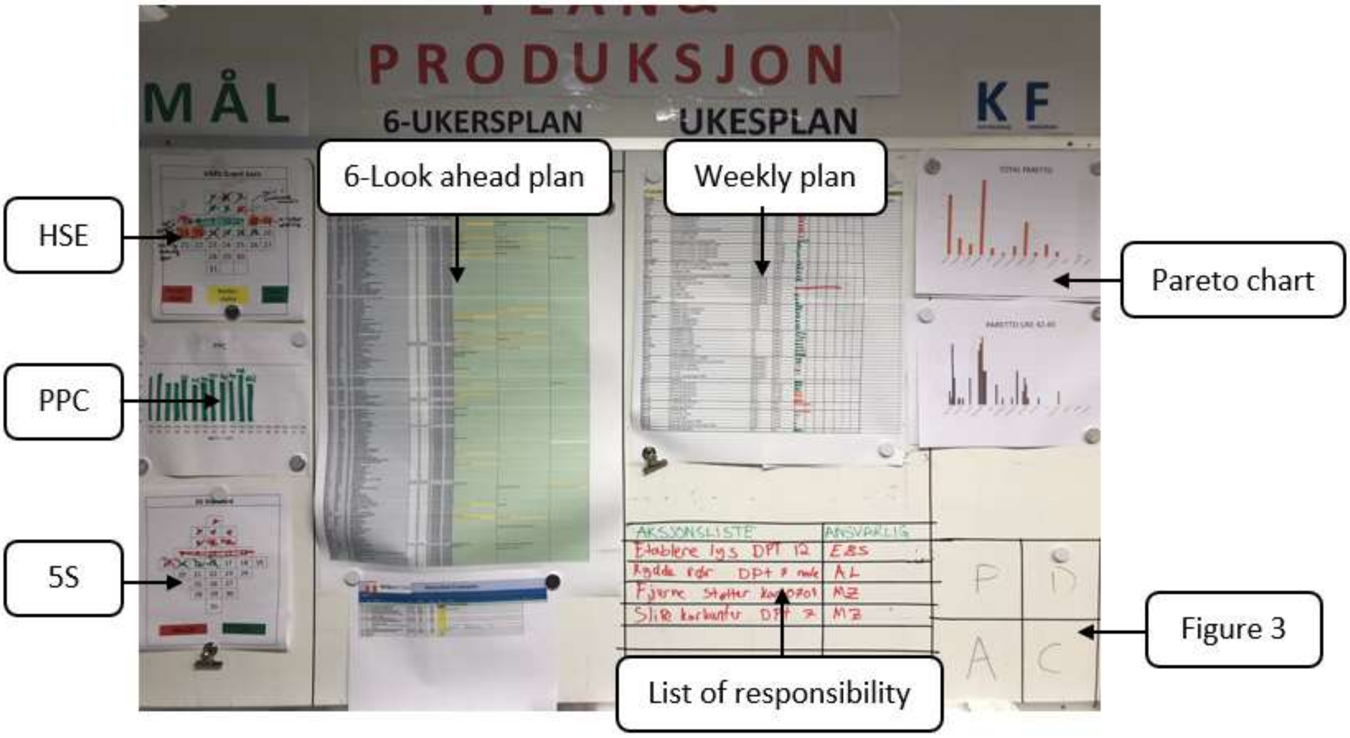

Figure 10 Information board at the Sjøtroll project [39]

Every week the project team sends out the task for the next week to the subcontractors. The subcontractor's answers with which tasks that are ready to start, and which are not. This is the project make ready plan. The one week make ready plan is summarized in the end of the week. The project team and the subcontractors go through the task that are finished and calculate the PPC. The informants explain that most of the subcontractors strive to get a high PPC every week.

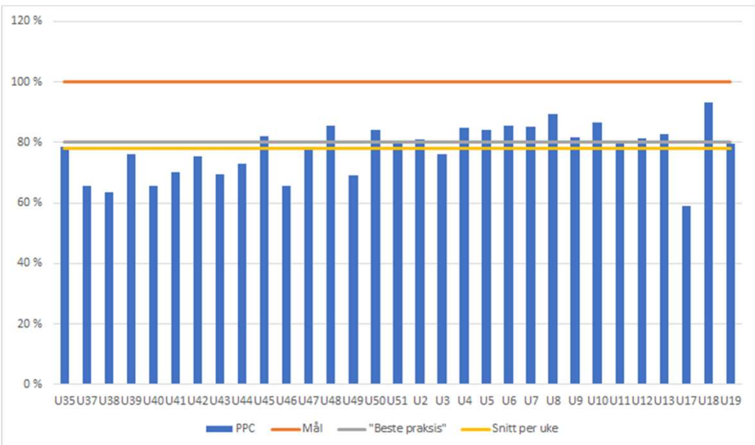

Figure 11 The Sjøtroll project's PPC [39]

Figure 11 shows the PPC calculated through the Sjøtroll project. PPC has gone up since the project started with Lean and Last Planner System. Meaning that more of the planned tasks for a week are finished on time. The goal will always be to reach a 100 % PPC. According to the informants, the best practice is 80 % in the construction industry. Total Betong AS has an average of 78% PPC per week during the project. In the morning meetings, constraints are explained and written down. The project team keeps a log of the constraints. During the project, the constraints are analysed and gathered in a Pareto chart. After the project completion, the project team will start on their next project, without conducting a lesson learned meeting.

The informants from Total Betong AS believe that Lean and Last Planner System have improved the control the project team have in a project. The workshops made the subcontractors more involved in the planning when the project started using Lean and Last Planner System. Because of the involvement in the planning, the project cooperation became better than before Lean and Last Planner System. In addition, the subcontractors have more ownership of the project. To bring in an external consultant was necessary in the beginning of the project according to the informants. The external consultant helped the project team with a smooth transition from traditional plan to a Lean an Last Planner System plan. The informants think it is important to begin with some parts of the Lean methods and not all at once. Before Lean and Last Planner System, the project was divided into the trades. In the transition to Lean, the project is divided into zones making it easier to get the bigger picture of the project. The look ahead plan makes the planning more predictable for the project. The project participants feedback is that the Lean method gives the project a better overview and flow.

4.3 Lessons learned from the project cases

Lean construction and Last Planner Systems have been hard to implement in construction projects in Scandinavia. It appears, that the main reason for failing to implement Lean construction is too little knowledge about the concepts shared between the contractors. One might suggest that the subcontractors do not see the potential of Lean construction and appreciate the benefit it gives to them. The Sjøtroll project brought in a consultant to help the transition, this might have been the help the project team needed to successfully implement

Lean and Last Planner System. Understanding the Lean methods is imperative to increase quality with the method. Good communication is an important factor to understand the implementation of Lean. Understanding the Lean methods will increase workflow and reduce waste.

The project cases suggest that there still is easier for managers and contractors to fall back on the traditional way of managing a project. The traditional approach may be easier in terms of planning and execution. However, to reduce waste and improve productivity in the construction industry there is a need for new thinking. The Sjøtroll project supports the theory that Lean and Last Planner System will make the planning of project easier and more controlled. When the Sjøtroll project has successfully implemented Lean and Last Planner System, it is also achievable for other companies in the construction industry.

The case studies show that the workers have a hard time adjusting to the methods introduced by Lean and Last Planner System. Especially the control aspects of PPC and make ready plan have been hard to implement.

Total Betong AS does not make time for a lesson learned meeting before the next project. None of the other projects mentions a meeting after the completion of the project. A lessons learned meeting is where a project team and subcontractors meet and discuss the problems and find solutions that can improve future projects.

Summary of the project cases:

Case / Function	Frederikskaj 2	Musikhus Kvarteret	Urbygningen	Sjøtroll
Contractor	MT Højgaard A/S	A. Enggaard A/S	Statsbygg and Ministry of Education and Research	Total Betong AS
Building period	2016/17, not specified	2014-2016	2013-2017	2017-2019
Project type	New	New	Rehabilitation	New
Master schedule	Used and updated	Used, not updated	-	Used
Phase schedule	Used, not pull planning	Used traditional	Collaboration meeting	Workshop
Meetings	Kick-off, weekly	Weekly	14-10-8-4-1 weeks meeting	6-1 and 4 weekly meetings
Look ahead plan	Used, 5 weeks look ahead plan	-	Used in the beginning	Used, 6-1 week
PPC	Used simplified method	-	-	Used
Takt time	-	-	Failed	-
Lessons learned	More communication between contractors. Workforce should not be stressed through the project.	Should analyse the reasons for the problems using “5 why’s?” More communications with a work ready plan to avoid misunderstandings.	Participant need more understanding of Lean construction.	Needs to think long-term. Could use other programs.

Table 5 Overview of Lean tools used in other projects

5 Building Information Modelling

This chapter will present BIM and explain how BIM relates to Lean. Synchro software will be explained in the last section.

5.1 What is Building Information Modelling?

> *"BIM (Building Information Modelling) is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure." [39]*

Building information modelling (BIM) is used by architecture, engineering and construction industry. BIM is a tool where all information about a construction can be gathered in one model. Technology makes it possible to have a BIM of new constructions. A BIM can be a 3-dimensional model of the project, with the construction details and the properties for all the elements going into the construction. Every component in the building can be given detailed information, including load bearing capacity, area quantities and material [40].

The BIM helps to exchange the information describing the project and can avoid problems caused by the lack of communication. Using such a model, everyone involved can alter the settings. The model will compute changes and show and how it affects the drawing of the building. If the architect has modelled the building using BIM, the engineer can set the requirements for the bearing structure. The software can show where mistakes are, like overlapping ducts and electrical installations. This way errors that would have delayed the project, are resolved before the construction starts. It is easier to rectify mistakes in the planning stage than at the construction site. In addition, BIM can be used after the construction is complete. When a problem occurs in the construction, or the owner wants to make changes to the building, all information needed will be in the BIM of the building. Therefore, it will also save time in the lifetime of the construction.

Norwegians are among the earliest adopters of BIM according to literature [41]. BIM is a method which helps the contractors and clients to visualize information. A model in BIM can be categorized into dimensions, the most common are 2 and 3 dimensional. It appears that 3D BIM is used more often in Norwegian projects, 4D is still in the start phase. Skanska, a multinational construction and development company, is trying out the 4D BIM in pilot projects [42]. A task group was set up by the UK Government to specify the maturity levels of BIM. The task group specified the level 0 to level 4 as of now [43].

Level 0 consists of information exchanged as drawings, text on paper or electronic documents, also known as CAD (Computer aided design) [41]

Level 1 is managing CAD in 2D and 3D information models. There is a collaboration between objects and files [40].

Level 2, a library management is added. This means that data can be shared between all parties, but not necessarily on the same model [41].

Level 3 it is expected that there will be full collaboration between parties. To have a seamless transition of the project model. Removing risk of conflicting information [5]. This can be done with Open BIM [41].

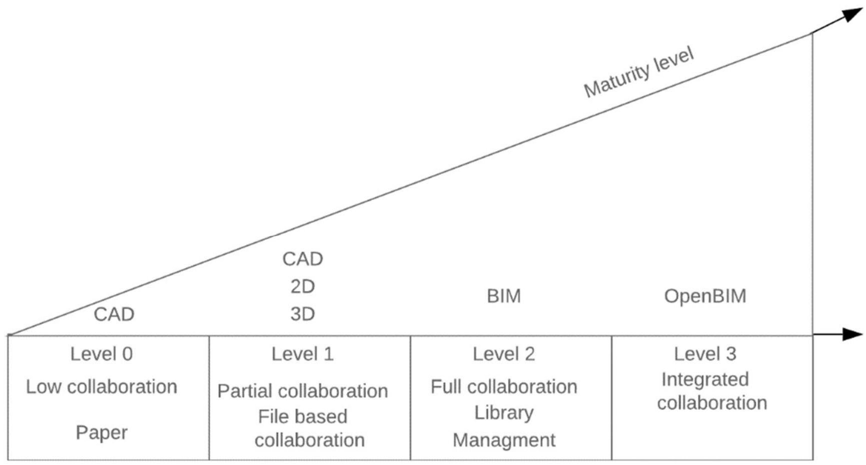

Figure 12 BIM maturity level, based on UK Government [43]

BIM is still developing, and more dimensions can be included. 4-dimensional use of BIM includes scheduling and can be used for planning the construction site [42]. This will increase the level of information given in the model. Time is added to the model so a video can show the construction in real time. The video can shove obstacles not thought of earlier in the planning process [44].

The 5-dimensional stage is entailing budget tracking and cost analysis. Visualizing the model in 5D will give the project a more precise estimate and more predictability of changes. The next step in dimensions is 6D. In 6D an energy analysis and heat frame are included. This helps to improve the building in the design phase and document the building for energy certification.

The 7-dimension makes it easier to predict the life cycle of the building by including information about the facility services. All information about the building will be included in the model and will help to maintain it. When changes are to be made to the building, it is easy to find out everything that is needed in the model [42]. For information flow in BIM there is important for files to be available for everyone.

IFC (Industrial Foundation Classes) is an open standardized file format. This format makes it easier to share BIM and information between different software applications that can compute this data. It is important that information can be exchanged between the software's available in the market. The different disciplines may use different software applications adapted for their purpose. Software that allows for information and BIM to be exchange in a file format as IFC provides, is called OpenBIM [41].

5.2 Interaction between Building Information Modelling and Lean

There has been extensive research, separately, on BIM and on Lean construction. BIM and Lean constructions are independent methods. However, since both are advanced technologies to assist the construction business in improving, there should be some correlation between the methods. In a journal, "Interactions of Lean and Building Information Modelling in Construction", the authors found a lack of research on the interaction between BIM and Lean. After looking into the principles of the methods, the authors came up with a matrix showing positive and negative interactions between BIM and Lean. In their research they considered 24 Lean principles and 18 BIM functionalities. 50 interactions are explained, out of these only 4 interactions were negative.

The most important positive interactions are listed below [45].

- Early functional evaluation of design.
- BIM makes it easier to understand the design, for clients and stakeholders.

- A 3D drawing helps to understand complex products.
- Reduces the rework, by helping the workers understand the drawings and decreases the chance of misunderstandings.
- Evaluation of impact of the design is possible in 3D.
- Decreases the chance of human errors
- Information is always up to date in the shared files. Everyone involved have the latest version.

The matrix shows that BIM functions helps to reduce the variables and the cycle time, these are Lean principals. Quality of the finished product is increased with the use of BIM and Lean together.

5.3 Synchro software

Synchro software is a computer program, which is made to improve the construction industry. It is a 4D BIM and Virtual Design and Construction (VDC) software platform [46]. The software is a connection for programs that can export IFC files. By connecting all drawings for ventilation, architects and others, the software will show a full model of the project. However, there are many difficulties when different programs are connected in one program. This thesis show experience with use of this software and is presented in section 6.4.

The Synchro software makes it possible to import IFC files, Microsoft Project files and Excel worksheet. The project schedule can also be done in Synchro project or be imported from Microsoft Project. When the plan is imported or planned in Synchro, the resources and the objects can be connected to the task. From the connection between task and 3D objects a 3-dimensional film, of how the building is constructed, can be made. The film can show if something is planned wrongly, as if a wall is built before the floor is finished, and help the workers to plan the project.

Synchro can show the full model as seen in Figure 27. To look at a specific part of the construction elements around can be unhooked. The figure will then only show the parts of interest. As in Figure 13 and Figure 14, where Figure 13 shows the reinforcement bars and their placement in the substation that will distribute power to the neighbourhood [47]. Figure 14 shows the sprinkler system in the rehabilitation building Alexander.

How Synchro can be used to implement Last Planner System will be explained in the section 6.4.

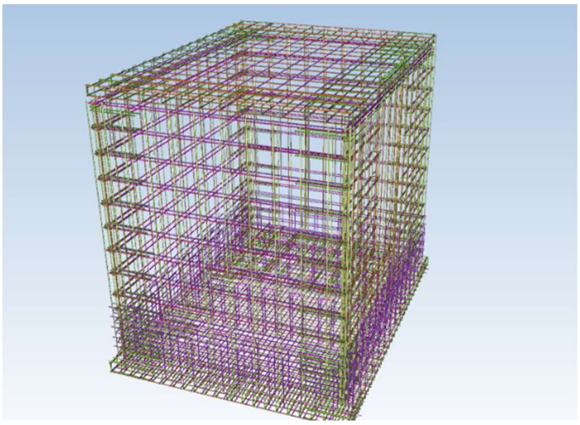

Figure 13 Reinforcement substation screenshot [48]

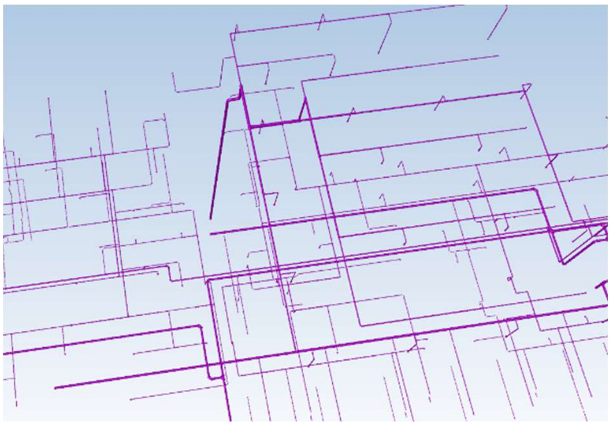

Figure 14 Sprinkler system Alexander screenshot [48]

6 The case study of Ledaal Park

This chapter will explain how Backe Rogaland AS uses Lean and Last Planner System in their project at Ledaal Park. The project will first be introduced, followed by an overview of the tools used in the project. The last three sections, 6.3, 6.4, 6.5, are the authors of the thesis suggestions to changes in the project so the project can further improve.

Backe Rogaland AS is part of the Backe group, which is one of Norway's 10 biggest construction contractors (2017) [49]. Backe tries to use Lean in all their projects to improve how the project is executed. This chapter will present and study one of their projects, Ledaal Park, focusing on how Lean and Last Planner System is used. In the end suggestions to how Backe Rogaland AS can improve their projects, will be presented.

6.1 Ledaal Park project introduction

Backe Rogaland AS was chosen as the turnkey contractor for the project Ledaal Park. The owner is Base Bolig AS and the architect firm behind the project is Brandsbergs Dahls.

Ledaal Park
•Contractor: Backe Rogaland AS •Stavanger, Norway •Contract value: 200 millions NOK •Total gross area 5000 m^2 •Building periode: 2018-2020 •Rehabilitation and new apartments

Table 6 The Ledaal Park project information

The Ledaal Park project consists of two buildings, called Alexander and Niels Juel. Alexander is the rehabilitation of Norges Hermetikkfagskole (The Norwegian Canning School), located along Alexander Kiellands gate. The building will have 22 apartments and an industrial area on the first floor. Alexanders total gross area is about 5000 m^2. The façade on Alexander is protected for cultural heritage, as well as the entrance, staircase, elevator and ballroom. Elements can be removed, maintained and then returned to the original appearance [50]. Niels Juel is a new apartment building constructed in Niels Juels gate. There will be 14 apartments with a total gross area approximately 4200 m^2 [51]. The project is set to be completed by summer 2020, the contract value of the project is around 200 million NOK [52].

Figure 15 Illustration of the project [51]

6.2 Current project planning process

Information given in this section is collected from an interview with an informant from Backe Rogaland AS on 3rd of May of 2019. The informant is involved in the planning and execution of the Ledaal Park project.

The project planners have used Lean thinking to plan Ledaal Park. As with other Lean projects, the Ledaal Park project is more detailed the closer the planning is to the date of execution. At Ledaal Park project the master- and phase schedule is included in the same document sheet, which is called the Lean plan. The master plan included the start date and the final delivery of the project. The milestones have been revised through the project as contractors have been added to the project and as the customers have change their mind.

The phase planning was done in a meeting with the subcontractors using sticky notes. Figure 16 shows a picture from the phase plan meeting at Ledaal Park using sticky notes. After the meeting the plan was transferred to a digital flow chart and shared with all participants. The Ledaal Park project uses both push and pull planning in the project. A pull plan was developed at the project's starting point. However, a combined push and pull plan was later created in order to meet the promised delivery date. The plan calculates what needs to be done and how much the project team needs to push the work from their current place. This is exemplified by the following situation, where the owner wants the industrial companies to move in before the rest of the building is finished. This means that some tasks must be moved up, such as the ventilation system for the whole building. The ventilation must be approved before the industrial company can move into the premises. This can be done by installing a temporary system and replace it later when the ventilation in the rest of the building is ready to be installed.

Figure 16 Phase planning for the Ledaal Park project [55]

Because the project is in an early phase, the look ahead plan is not used. In the beginning of the project the project team only use the detailed Lean plan. When the project starts with the Takt plan, the project will try to use 3 weeks look ahead plan. Other documents used are a duration matrix to find the Takt plan for the projects, a sheet explaining the zones and activities in each phase of the project and a flow chart of the tasks.

The project tries to follow a Takt plan. When something interrupts the plan, the project team tries to clarify the dates for the task, so the task is completed by the promised date. In the rehabilitation of Alexander, the structural design has been delayed from the beginning. The delay is caused by unanticipated obstacles. The informant believes it will be easier to follow a Takt in a new building like Niels Juels, as there will be fewer problems discovered during the building process. However, a new building can also have problems delaying the project. Regarding Niels Juel, the issues began with the groundwork. The sheet pile walls hit rocks when they were placed in the ground. The walls broke as a result of this, and the machine broke while removing the broken walls. There was therefore a need for an alternative method, which according to the informant, never has been used in Norway. The delays with Alexander and Niels Juel have resulted in the project running on a tight schedule.

PPC is not calculated in the project. Backe uses an Excel sheet for describing the constraints that occurs in the project. The project manager writes down constraints during the progress meeting. The constraints are divided between the responsible companies. Delays caused by the constraints are also in the document sheet. Backe does not record the reasons for constraint in a Pareto chart. The informant believes a Pareto chart would take up too much time to fill in during the meetings. The informant explains that some Backe projects use it by asking the contractors write the information down on sticky notes during the meeting. Afterwards the project leader can gather these notes and transfer the information to the other documents. The problem with this is that information might be interpreted wrong, or there is need for more information. Ledaal Park mark delays in the project in, the Lean plan, with red colour. Current status of the task is marked in the Lean plan and finished work is struck through.

The project controls how much should have been done, by checking the economy. Every trade has a financial budget. If concrete have used 30 % of their budget, then 30 % of the concrete work should be done. If 30 % of the budget is used, but only 20 % of the concrete work is done, the concrete is running over budget and should be investigated. The project has a risk budget for unforeseen problems, this includes problems with the building during the five years of responsibility after delivery. The risk budget must therefore only be used if absolutely necessary.

During the project, a great deal of the resources are spent on the apartments, which can be customised by the buyers. All changes to the original plan must be researched by engineers to consider their costs and whether they are achievable. Additionally, some changes must be approved by the Cultural Heritage Management Office. Backe Rogaland AS has hired a person to communicate with the customers and make sure all changes are taken care of in the project. This has however been challenging, due to indecision among the customers. According to the informant, customers have wanted to make certain changes, only to change their mind once the customer discover that the new solution is more expensive. This has resulted in extra work for the engineers.

In order to work on Backe Rogaland AS projects the contractors must participate in a Lean course. The course is made for them to get familiar with the methods used in Lean, that are explained in chapter 3. The informant explains that after a project is done, the project team starts on the next project without taking time to discuss the completed project.

Lean and Last planner tools are to a degree used in the Ledaal Park project. The project team is figuring out which Lean tools that works and which does not for their project. The Lean plan includes a master schedule and phase planning. The project team has not managed to make a look ahead plan for the project at this time. Pull planning has been tried, but the project still pushes the plan through. During the project constraints are marked in the Lean plan but are not controlled.

Summary of the Ledaal project:

Case / Function	Ledaal Park Alexander and Niels Juels
Project owner	Backe Rogaland AS
Building period	2019/2020
Project type	New and Rehabilitation
Master schedule	Used and updated
Phase schedule	Used, a combination of pull and push planning
Meetings	Kick-off, weekly
Look ahead plan	To be used. Not used in the project as of today.
PPC	Not used. Notes on constraints in the Lean plan
Takt time	Used
Lessons learned	Still in the start phase of the project.

Table 7 Overview of Lean tools used in Ledaal Park

Figure 17 shows the current planning process within the Ledaal Park project. The current status in the company dictates how the project will be planned. The project team uses Excel to make a Lean plan and a Takt plan. The master plan and the phase plan are included in the Lean plan. From the Lean plan the constraint log is produced. For the next project, the planning process will be the same.

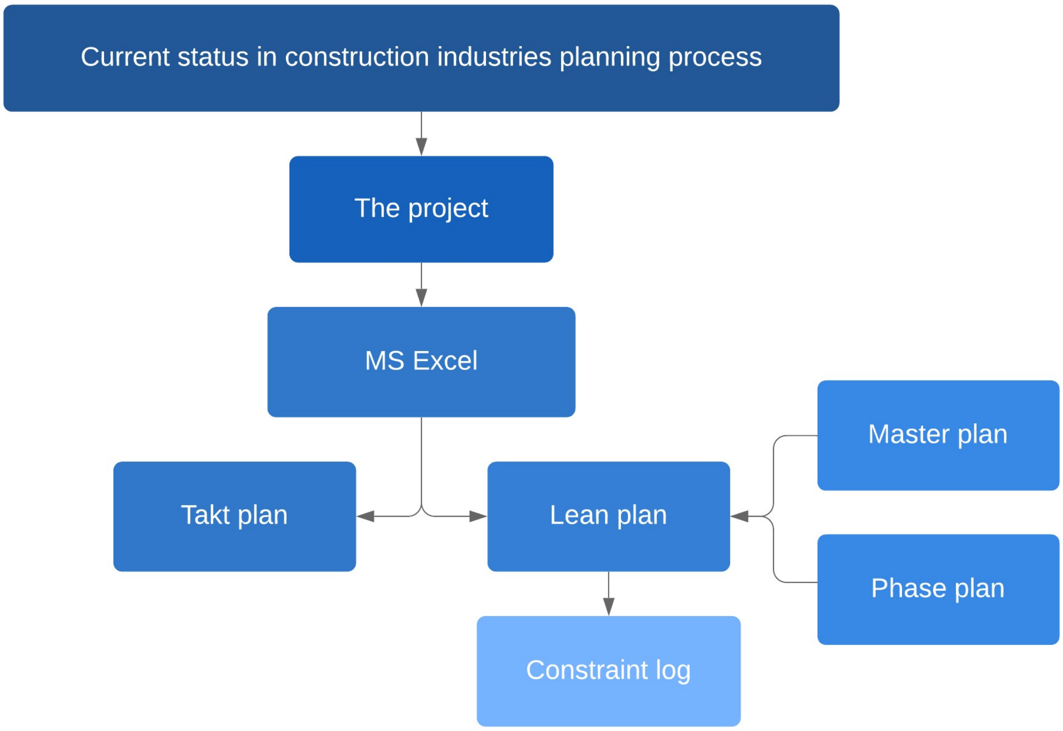

Figure 17 Flow chart of current situation

6.3 Suggested improvements

Suggestions to how Backe Rogaland AS can improve their project with Lean and Last planner given by the author of this thesis will be presented. The visual images presented are made in Microsoft Excel. The task are examples to show how the document functions. See appendix B for the formulas in the Excel worksheet.

To help Backe Rogaland AS improve their planning process, the author of this thesis made an Excel worksheet. The content in the worksheet, and how the sheet works, is described in the sections underneath.

The Excel worksheet contains:

- Lean plan
- Takt plan
- Look ahead plan/Make ready plan
- Constraint log
- Pareto chart
- PPC

One of the problems, Backe Rogaland AS seems to have, is to many documents. The project team has different documents for the Lean plan, Takt plan and phase explanation. Some of the documents that are available are not used because of the inconvenience in the meetings. The project leader wants the meetings to run efficiently. Using many different documents that does not work together is a waste of time. Collecting all these documents into one, makes it is easier to stay updated on the development in the project. The worksheet can be shared with an internet link. This way any updates are easily shared with everyone in the project. The first sheet in the document is the main Lean plan, see Figure 19.

6.3.1 Lean plan

The author of this thesis has redesigned the Lean plan for the project, see Figure 19. The first information in the plan is the name of the project, the start date, todays date and the last updated date. Start date is connected to the project timeline dates. Today's date will change according to the present day. The project timeline dates are depending on the task's dates in the project and will change when the task dates are changed. The earliest task given will also be the projects start date, and the latest task is the end of the project. The phase dates will change according to the task in the phases. The tasks in one phase are grouped together to make it easier to look at one phase. When a task is given a start and finishing date, the calendar will mark the original plan dark blue with number 2. If the actual dates are different from the original plan, the dates will be lighter blue and with number 1 in the cell.

The status of the task can be changed between:

- Not started
- On track
- Delayed
- Finished

Figure 18 shows a picture of the coloum in the worksheet.To change the status, click on the cell and a box with a downword arrow appaer. When clicking on the arrow, the list of choices will show and the right status for the task can be chosen. If a task has a constraint it can be marked with a "x" in the Lean plan. When a task is marked the task will automaticially be transferd to the constraint log. The constraint log will be explained in section 0.

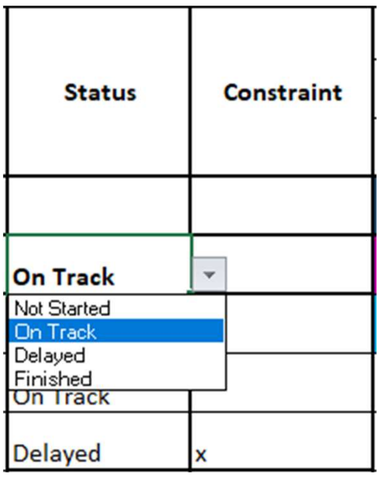

Figure 18 Status of tasks. Extract from the Lean plan

This Lean plan schedule makes it easier to change the date for the tasks and tell if the task is started, on track, delayed or finished. The colour coding shows which contractor is doing the task.

Lean plan

Project name:	Ledaal Park	Explanation:	
Start date:	31.12.2018		
Date today	11.05.2019	Original plan	2
Last updated:	10.05.2019	New plan	1

Contractor 1	Contractor 4
Contractor 2	Contractor 5
Contractor 3	Contractor 6
Contractor 7	
Contractor 8	
Contractor 9	

Color coding	Reference	Task description	Building	Floor	Original plan		New plan		Comment	Status	Constraint
					Start date	Finnish date	Start date	Finnish date			
	Project Timeline				**31. des. 2018**	**25. feb. 2019**	**31. des. 2018**	**26. feb. 2019**			
	Phase 1		B1	1. etg	**31.12.18**	**15.01.19**	**31.12.18**	**15.01.19**		**Not started**	
	Task 1a				31.12.18	01.01.19	31.12.18	01.01.19		Finnished	x
	Task 1b				01.01.19	03.01.19	01.01.19	03.01.19		On Track	
	Task 2				01.01.19	02.01.19	03.01.19	04.01.19		Delayed	x
	Task 3				02.01.19	04.01.19	02.01.19	04.01.19		Not started	
	Task 4				04.01.19	06.01.19	04.01.19	06.01.19		Not started	
	Task 5				08.01.19	14.01.19	08.01.19	14.01.19		Not started	
	Task 6				09.01.19	10.01.19	09.01.19	12.01.19		Not started	
	Task 7				09.01.19	10.01.19	09.01.19	10.01.19		Not started	
	Task 8				05.01.19	13.01.19	05.01.19	13.01.19		Not started	
	Task 9				03.01.19	07.01.19	02.01.19	06.01.19		Not started	
	Task 10				08.01.19	12.01.19	08.01.19	12.01.19		Not started	
	Task 11				12.01.19	13.01.19	12.01.19	14.01.19		Not started	
	Task 12				13.01.19	15.01.19	13.01.19	15.01.19		Not started	
	Task 13				01.01.19	03.01.19	02.01.19	04.01.19		Not started	
	Phase 2		B1	2. etg	**16.01.19**	**07.02.19**	**16.01.19**	**07.02.19**		**Not started**	
	Phase 3		B2	1. etg	**08.02.19**	**25.02.19**	**08.02.19**	**26.02.19**		**Not started**	

Reference	Week 1					Week 2					Week 3						
	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu
	31.12.	1.1.	2.1.	3.1.	4.1.	6.1.	7.1.	8.1.	9.1.	10.1.	12.1.	13.1.	14.1.	15.1.	16.1.	18.1.	19.1.
Project Timeline	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Phase 1	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
Task 1a	2	2															
Task 1b		2	2	2													
Task 2		2	2	1	1												
Task 3			2	2	2												
Task 4					2	2											
Task 5								2	2	2	2	2	2				
Task 6									2	2	1						
Task 7									2	2							
Task 8						2	2	2	2	2	2	2					
Task 9			1	2	2	2	2										
Task 10								2	2	2	2						
Task 11											2	2	1				
Task 12												2	2	2			
Task 13		2	2	2	1												
Phase 2															2	2	2
Phase 3																	

Figure 19 Lean plan template

6.3.2 Takt plan

The Takt plan template is used to find the Takt time in the project. Contractor tells how many labour hours each task will take. The bar chart gives a visual image of the labour days. Seeing the average labour days, helps the planner finding the Takt time. Figure 20 shows the Takt plan template with an example. In this example the average is 3.2 days, suggesting that the Takt time should either be 3 or 4 days. Depending on what the planner decides for the Takt time, the task must be arranged so all tasks have either enough time or crew to keep the Takt in the project.

Takt plan

Project name: Ledaal Park
Avarage labour days: 3,2

Contractor	Tasks	Labour days
Contractor 1	Foundation	6
Contractor 1	Isolation ground	2
Contractor 2	Plumbing	3
Contractor 3	Electrical	3
Contractor 4	Assembeling walls	2

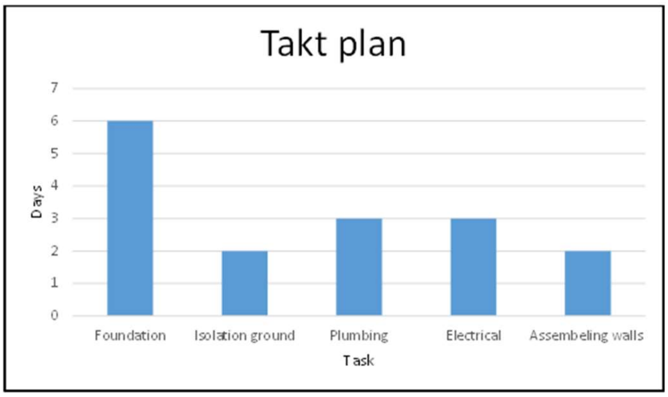

Figure 20 Takt plan template

6.3.3 Look ahead plan

The look ahead template, made for this thesis, shows if a task is ready to start or not. Figure 21 shows the Excel sheet called “Make work ready”. The name of the Excel template is chosen to describe what the sheet does, making work ready to be performed. A Look ahead plan, as described in section 3.3.3, can be made from 8 to 1 week, depending on the project management wishes. If the project manager wishes to use many look ahead plans it should be explained in the template to avoid confusion. The template is easily changed between 8-1 week, by adding the task for the number of weeks agreed to look ahead. For 4 weeks look ahead plan, the task for 4 weeks is added in the template under the contractor that will perform the task.

Make ready plan

Contractor 1

Project name:	Ledaal Park	Contractor:		No. Of Tasks:	10
Phase:		Manager:		No. Of Tasks done	6
Area:		Responsible person:	RG	PPC:	60,00 %
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments
1	Task 1		Yes								Yes	
2	Task 2		No		RG						No	
3	Task 3		Yes								Yes	
4	Task 4		Yes								Yes	
5	Task 5		No			RG					No	
6	Task 6		Yes								Yes	
7	Task 7		No		RG					RG	No	
8	Task 8		Yes								Yes	
9	Task 9		No					RG			No	
10	Task 10		Yes								Yes	

Contractor 2

Project name:	Ledaal Park	Contractor:		No. Of Tasks:	8
Phase:		Manager:		No. Of Tasks done	4
Area:		Responsible person:	MD	PPC:	50,00 %
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments
1	Task 1		Yes								Yes	
2	Task 2		No		MD						No	
3	Task 3		Yes								Yes	
4	Task 4		No			MD					No	
5	Task 5		No						MD		No	
6	Task 6		Yes								Yes	
7	Task 7		Yes								Yes	
8	Task 8		No		MD						No	
9												
10												

Figure 21 Make ready plan template

The make ready plan is filed out by the person responsible in the company. The person responsible for the tasks is given in the information box. In the checklist the person will mark with their initials the condition that prevents the task from being ready. When a cell is marked with initials, the ready column will automatically change from yes to no. In the ready column and the finished column, a cell will change colour if it is yes or no. Green is yes and no is red. This will visualize more clearly if tasks are healthy to start. Number of tasks, and number of tasks that are finished, are calculated and is written in the top right corner. PPC for the contractor for one week is then calculated.

6.3.4 Constraint log

Figure 22 shows the constraint log template designed by the author of this thesis. The constraint log, as mentioned in section 0, is connected to the Lean plan. In the Lean plan one of the columns is constraint. If a cell in the constraint column is marked, the related task will be transferred to the constraint log sheet, both the task reference number and description.

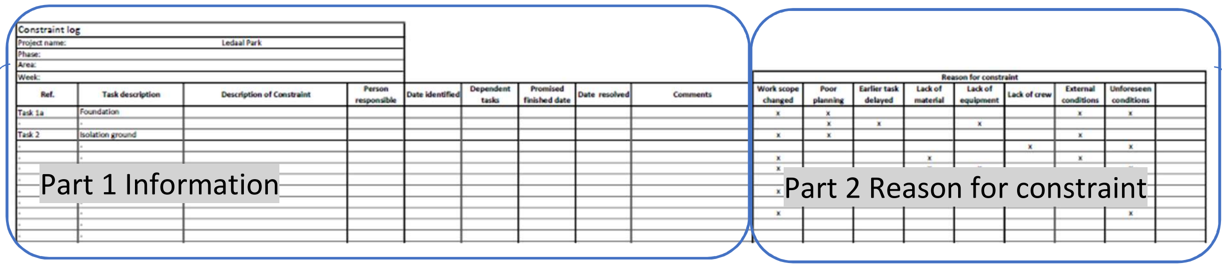

Figure 22 Constraint log template

Constraint log								
Project name:		Ledaal Park						
Phase:								
Area:								
Week:								
Ref.	**Task description**	**Description of Constraint**	**Person responsible**	**Date identified**	**Dependent tasks**	**Promised finished date**	**Date resolved**	**Comments**
Task 1a	Foundation							
-	-							
Task 2	Isolation ground							
-	-							
-	-							
-	-							
-	-							
-	-							
-	-							
-	-							

Figure 23 Constraint log template, Part 1 Information

Reason for constraint							
Work scope changed	**Poor planning**	**Earlier task delayed**	**Lack of material**	**Lack of equipment**	**Lack of crew**	**External conditions**	**Unforeseen conditions**
x	x					x	x
	x	x		x			
x	x					x	
					x		x
x			x			x	
x			x	x			x
	x			x			
x		x					x
x							x

Figure 24 Constraint log template, Part 2 Reason for constraint

When the contractors meet to discuss the project with the project manager, the project manager can easily write down the information for the constraint. Information on the task includes the responsible person, dates for the task, description of the constraint and dependent tasks.

Pareto chart	
Project name:	Ledaal Park
Phase:	
Area:	
Reasons for constraint	Total no.
Unforeseen conditions	5
Work scope changed	5
Lack of equipment	3
Poor planning	3
Lack of material	2
Earlier task delayed	2
External conditions	2
Lack of crew	1

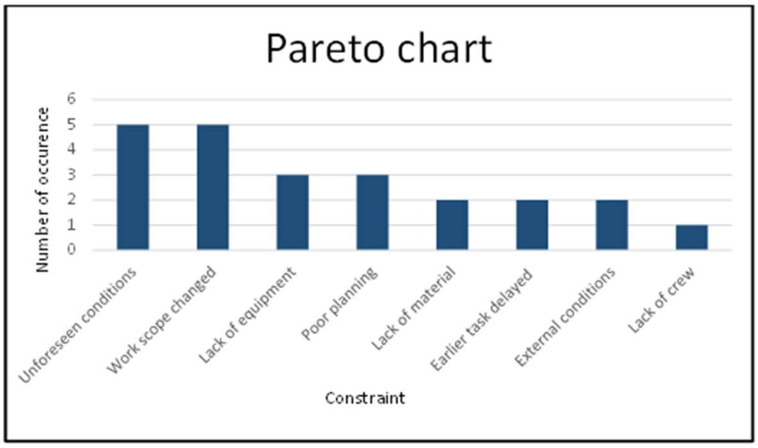

Figure 25 Pareto chart template

The reason for the constraints can be marked with an “x”. For every reason that is marked in the constraint log, the pareto chart will be updated. The pareto chart sorts the reason for constraint after which occurs most often. Figure 25 shows the pareto chart template. The total number of each constraint is gathered from the number of cells that are marked with “x” in the constraint log. By clicking on the arrow beside “Total no.” and choosing “sort from largest to smallest”, the bar chart will have the bars sorted from highest number of occurrences to lowest.

6.3.5 PPC

In the make ready plan the number of tasks planned and the number of task finished are counted. From those the PPC is calculated. The result from each subcontractor is transferd to the the PPC sheet automatically. Here the avarage for every week in the project is calculated. The graph in Figure 26 shows how the project is performing. When the PPC is high the project gets the planned tasks done. This is a tool to help the project leader. The sheet easily shows if a contractor is doing the work they have promised, or not, because the PPC is calculated separately for each subcontractor.

PPC

Project name: Ledaal Park

Week	Contractor 1	Contractor 2	Total
Week 1	60,00 %	50,00 %	55,00 %
Week 2	75,00 %	62,50 %	68,75 %
Week 3	60,00 %	75,00 %	67,50 %
Week 4	66,67 %	62,50 %	64,58 %
Week 5	71,43 %	77,78 %	74,60 %

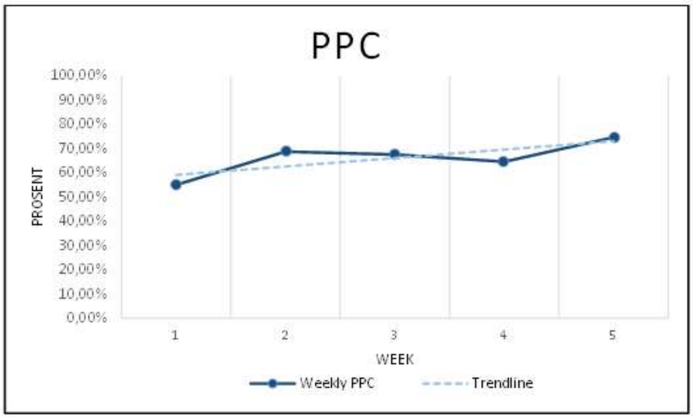

Figure 26 PPC template

6.4 Synchro used in Last Planner System

This section explains how Synchro software can be used in a project. Synchro has an option called task filters. Tasks can be showed depending on whether the task has started, finished or if there is need to look ahead in the schedule. A look ahead plan can either show planned tasks for one or two weeks ahead in the schedule of the chosen time. The critical path is also accessed here and will show the tasks that are in the critical path. Scheduling report will show a summary of the project and the tasks, how many tasks that are planned, in progress or complete. This can be used to make a PPC. The software does not develop a PPC but will simplify the process of making one.

Backe Rogaland AS has provided the IFC files from their project at Ledaal Park to be used in this thesis. The calendar dates are fictive and does not represent the project real planned dates. Figure 27 explains the elements in the Synchro software.

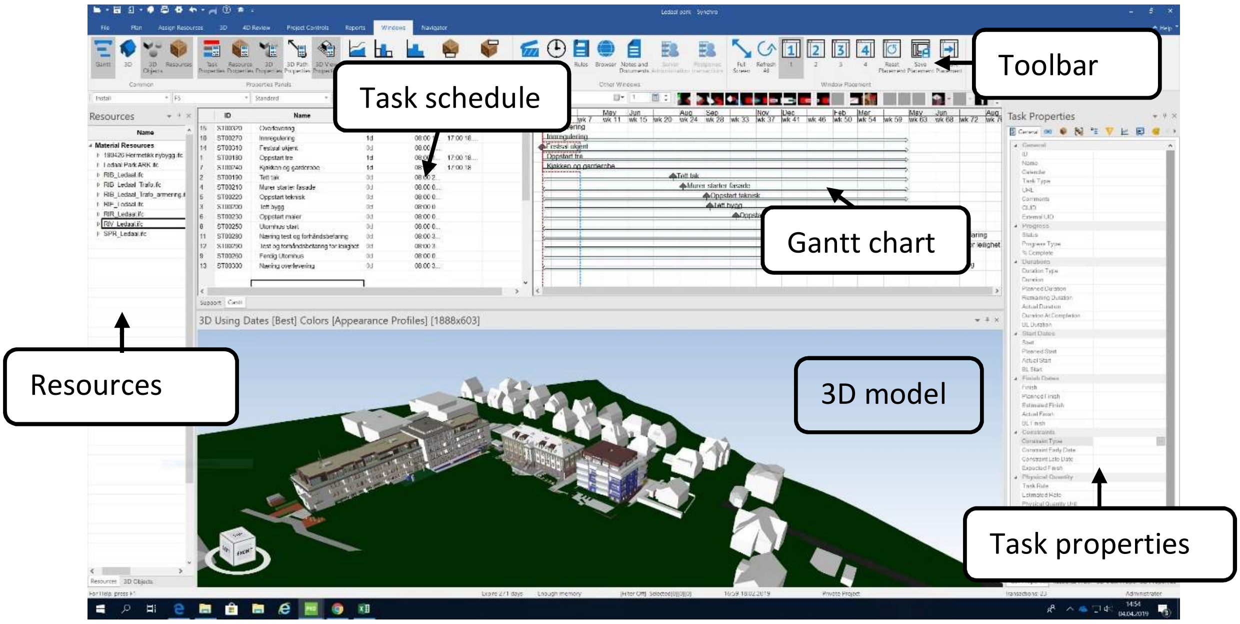

Figure 27 Screen photo of Synchro software [48]

Figure 28 shows a traditional way to plan the project compared to the project planned with Synchro in Figure 29. As seen in the figures the Synchro project planning gives more information on the project. The columns can be customized depending on what is needed of information. If task is delayed, it is easy to change the duration and see how the other task will be affected by the change. The traditional way of planning in Excel has less information included. If a task is moved in Excel, connected tasks must be moved manually. Excel is therefore a more time-consuming planning software.

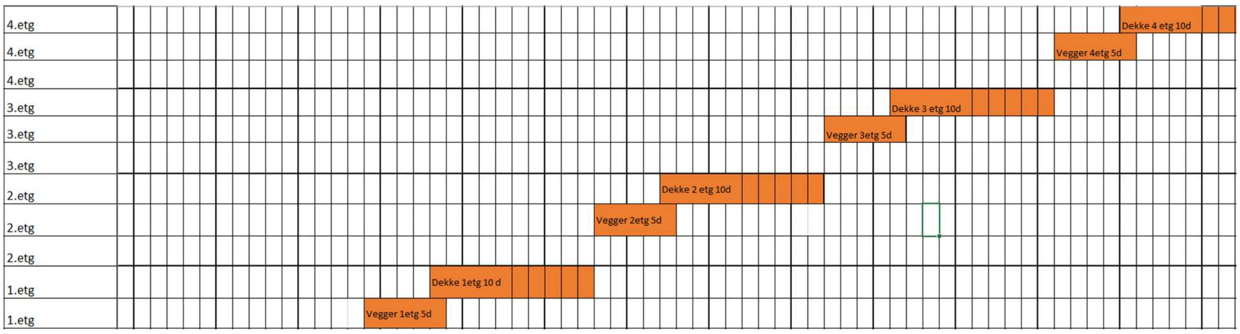

Figure 28 Traditional planning [53]

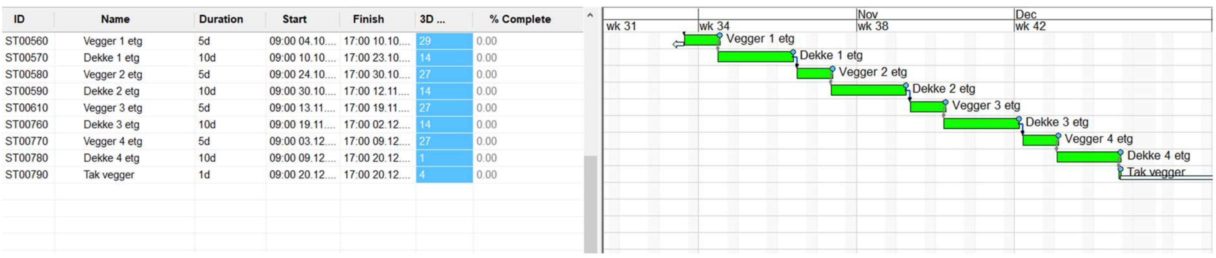

Figure 29 Synchro planning [47]

Adding customized columns in the Gantt chart in the program can help the project manager. A make ready plan can be made in these columns. By adding constraints as columns. The corresponding cell have a number "0" if the conditions are not met for the task and "1" if the conditions are met. If a task is ready, all constraints will have the number "1" and the task can be started. See Figure 30 Make ready plan in Synchro underneath for an example.

1. Information	2. Material	3. Crew	4. Equipment	5. Space	6. External Co...
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	0	1	1	1	1
1	1	1	0	1	1
1	1	1	0	1	0
1	0	1	1	1	1
1	1	1	1	0	1

Figure 30 Make ready plan in Synchro [48]

Synchro can make a video animation of the construction. For the video to be made elements in the building must be connected to the corresponding task. Meaning that a slab in the first floor is connected to the task where the slab is made. When all the elements in the construction is connected to a task, the video is made. The video will follow the schedule of the tasks and the elements connected to the task will appear. At the start of the video only the elements that are not attached to a task is shown, as landscape and surrounding buildings. For this thesis a video was made for the case study and is presented with a series of pictures from the video animation. See Figure 31. The red line shows which task that is active at the time. The elements connected to the active task are green in the 3D model.

Figure 31 shows a series of pictures. The series of pictures is to illustrate how a video animation made in Synchro would look. The red line moves with the dates, to show which dates that are active.

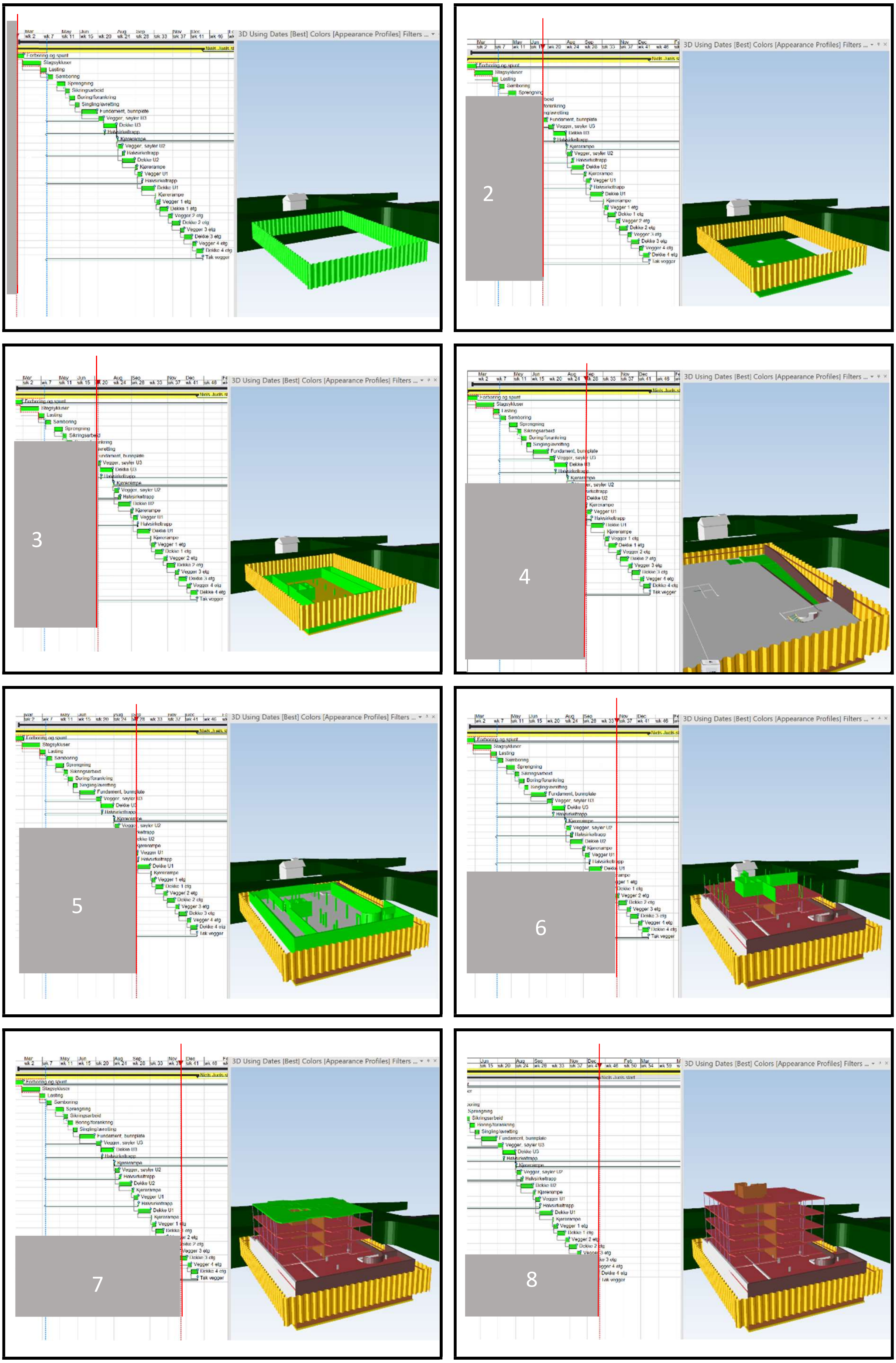

Figure 31 Synchro video animation [46]

6.4.1 Problems

One of the files from the architect, in the project at Ledaal Park, was not able to be imported into Synchro. This might be because of the program the architect uses ruins the files when transferred to a different format. There seems to be a problem in the industry that there is a lot of different software's and therefore many different formats. When a file is exported into a new format not all information is transferred properly, and therefore the file does not have the same informational benefits. The construction industry is a big market for software developers. If the software developers can get more companies to buy their product the developers earnings increase. Therefore, the developers make it harder for software files to be used in other formats. For example, if a plumber needs 5 different software's to work on 5 projects with different construction companies, it will not be sustainable for the plumber. It takes practise to learn some of the programs. In addition, it is expensive to maintain the licences to the software's. This problem should have been solved with the IFC format. It still seems that some of the programs do not transfer well into the IFC format.

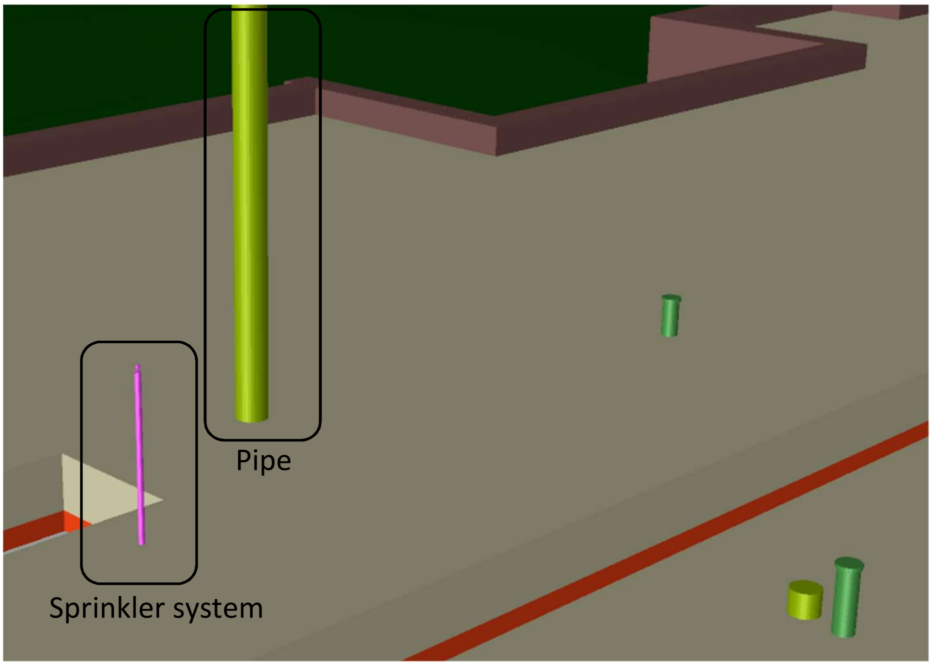

Figure 32 Alexander building roof [48]

Figure 32 is the roof of the renovating Alexander building. Here some pipes are coming out of the roof. This shows how the Synchro software can highlight problems with the drawings, and solve problems in the planning stage, which is easier than when the project has begun. The purple pipe is the sprinkler system in the building, it is not supposed to be sticking out of the roof.

6.5 The improved planning processes

Figure 33 shows a flow chart of the proposed improvements Backe Rogaland AS can do in their project. The current status will start the planning process in the project. Once the project has started the project team can decide to use both Excel and Synchro, or just one. Excel is explained in section 6.3 and Synchro is explained in section 6.4. After the project is completed, the project team can use gathered information from the planning process to improve the status in the company for the next project. Lessons learned in the project depends on the Lean tools and methods the project team uses.

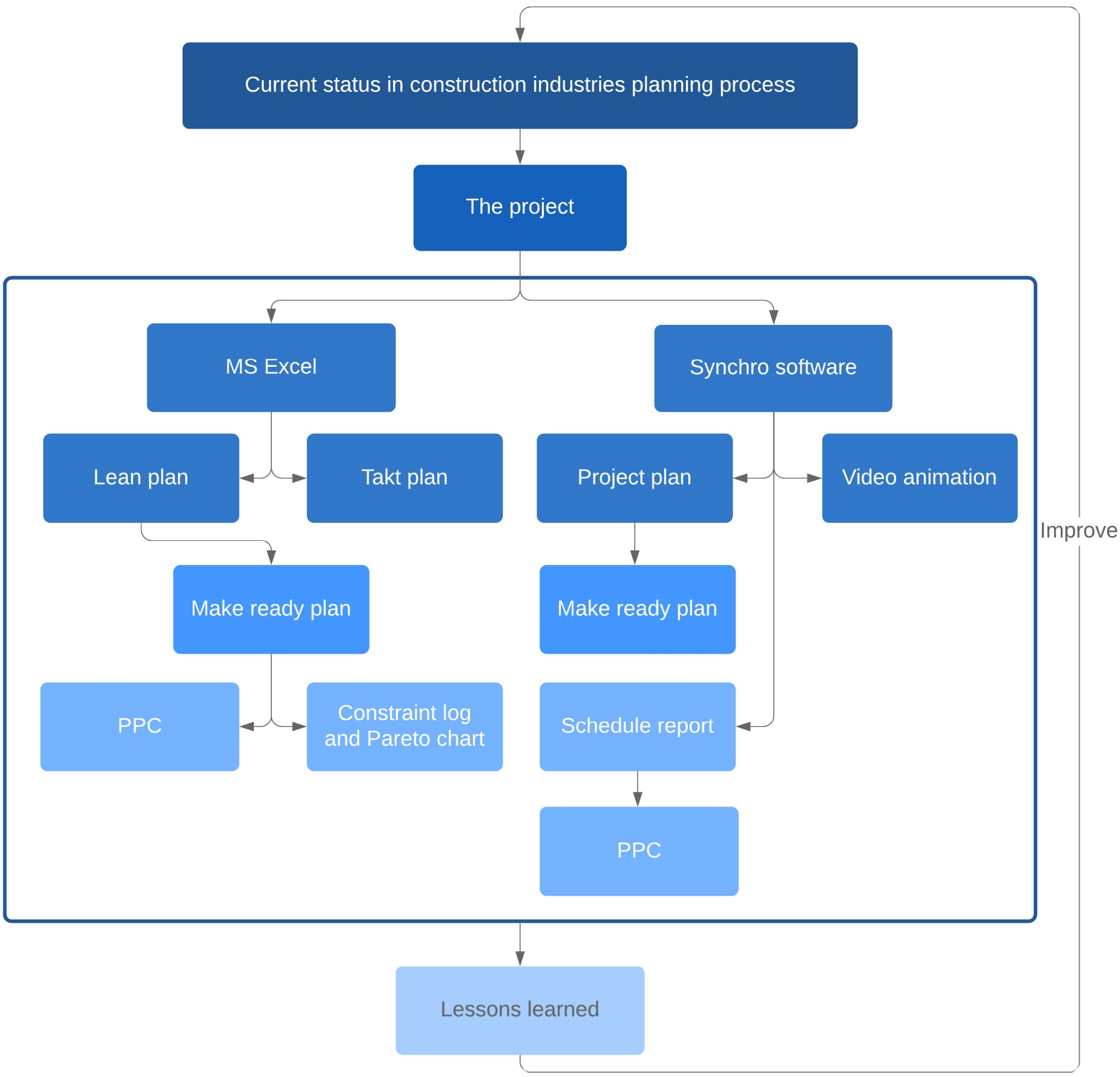

Figure 33 Flow chart of suggested improvements

7 Discussion and Conclusion

This thesis explains the use of Lean and Last Planner System. Lean and Last Planner System main goals are to increase productivity, quality, flow, and to reduce waste in construction projects.

Productivity increase can be achieved with the right planning process and better communication. Misunderstandings happen if there is poor communication within the project. Good quality increases the lifespan of a construction. A good flow in the project will increase production time and ensure delivery time. Planning the project with every task healthy, will help to reduce waste.

The following presents the positive and the negative aspects of the cases investigated in this thesis.

The Phase planning in the Frederikskaj project is conducted in collaboration with workers and subcontractors. Look ahead plan is discussed twice every week in meetings. This increases the accuracy of the plan. The project leader assessed the information gathered in the project as imprecise. The decision to work without a full PPC, arise partly from her experience that subcontractors tend to answer roughly. As a result, the project used a simplified PPC method to manage the progress of the tasks. The project report is well documented with the simplified PPC. The report indicates that the project was a stressful workplace. The stress on the workforce seems generated by the pressure to keep tasks on track.

In the Musikhus Kvarteret project, the subcontractors participated in the phase planning. However, the plan was pushed through the project. The project leader did nevertheless plan for one week ahead because of the uncertainties in the project. Causes for problems were not analysed during construction, or after the project completion. In the project, the contractors and the subcontractors showed a high level of trust towards one another. This is the product of cooperation in earlier projects. Last Planner System caused confusion in the project. The uncertainty might give cause to why the planning of the project was carried out in the more traditional way.

In Statsbygg project, Urbygningen, all subcontractors participated in a Lean course before starting the project. Phase planning was done in collaboration with the subcontractors. However, the goals of the meetings were not clear to those attending. The lack of clarification made the meetings useless to the participants. The Urbygningen project scheduled for many meetings to make the plan. During the project the meeting schedule changed to a 4-1-week. The reason for the change was the constant occurrence of unexpected problems in the project. The content and product of previous meetings was of less use when the managers had to agree on a new plan to carry out. On the other hand, the project got ahead of the problems. The meetings may have helped the project to foresee constraints and react earlier than they would have done without such meetings. BIM stations was a success in the project. The participants wished, for future projects, to have the model rooted higher up in the hierarchy, in order to have more details that are reliable in the drawings. Key persons lost ownership of the project when an external consultant came into the project. To bring in an external consultant might have done more harm than good. It seems the decision disturbed the project flow. The project started, during the construction, to use a traditional way of planning. Reasons for failures in the project is probably due to a combination of too little knowledge among the participants and trying to implement too many tools, at the same time.

In the Sjøtroll project, phase planning was done in workshop meetings with the subcontractors. From the workshops and the weekly meetings, the project team has experienced more control and better communication with the subcontractors. Subcontractors are more involved in the planning process. Such an approach makes the plan better from the start and onwards. Subcontractors agrees on the weekly plan before the week start, increasing the quality of the planning. The project team works more efficiently, because the plan for the task is made when it is needed. The PPC shows how the planning improved after the project started implementing Lean and Last Planner System. The project hired help from an external consultant to make the transition to Lean and Last Planner System. Bringing in a consultant helped the transition to go smoothly. The project started up by using some parts of the Lean tools and did not take all in at once.

The Ledaal Park project is in its making. The project uses a Lean plan that includes the master plan and the phase plan. The phase plan is made in participation with the subcontractors. Because of the problems in the beginning of the construction, the project uses both a push and a pull system. The project might have experienced incidents of misunderstandings caused by combining the systems of push as well as pull. Communicating with the customers is a challenge in the project. The project has decided to hire an extra person to take care of the communication between the contractor and the customers. The problem might have been greater without the extra person. It is difficult to say if using Lean in the project has reduced the communication challenges. However, it is possible to argue that the pull system has helped to an early discovery of future obstacles. The constraint log in the project is simple. The simplification makes the project not properly recorded. In the completion of the project, it might be difficult to analyse what incidents made an impact on the construction work. To investigate what caused constraints, and how different constraints were solved, more data would have made a difference. With the present log, the benefit will be limited. The project has different documents for the different plans and logs.

All projects considered

The different cases summarized above show different approaches in implementing Lean and Last Planner System. Furthermore, the cases show positive and negative experiences with Lean and Last Planner System, and there are diverse opinions on how successful the theory have turned out to be in an everyday use in the projects.

In all the cases, the project uses *a master plan*. In a few cases, the master plan is revised after involving the subcontractor. In some cases, they do not make any such alterations. The different approaches to how the master plan is utilized seems to have little effect on the further planning process in the projects. In the Excel worksheet made for this thesis, see section 6.3, the master plan is a part of the phase planning. Making these elements connect helps to see constraint in the plan. Milestones can be marked directly into the plan. Therefore, making it more visually.

In *the phase planning* the subcontractors are involved in most of the cases. The project team is positive for the collaboration with the subcontractors and experience more understanding between the trades and other participants in the project. The exception is in Statsbyggs project, where the purpose of the phase plan meeting was not obvious to the participants. In Statsbyggs case, the participants in hindsight understood that the objectives of the meeting were not explained to them. Providing such an explanation at the start up would have clarified how a phase plan can make an impact on the construction work and made the meeting more constructive. Having the phase plan and the master plan in the same documents clarifies the plan in the meeting. Each phase goes from one milestone to the next milestone. In the Excel worksheet mentioned above, this is done. The worksheet makes the project visual and it becomes easier to give all participants a common understanding of the aspects of the project. The phases are a collection of tasks that must be performed to meet the goal of the milestone set in the planning. In the excel worksheet it is possible to show one phase at a time. This way it is made possible to concentrate separately on each of the tasks in the phase without losing oversight of the project in all.

The number of meetings varies in each case. The cases studied with most success have a longer *look ahead plan* (6-4 weeks), and a weekly plan (one week ahead). The difference between 4 or 6 weeks look ahead plan seems minimal. What is most important is to consider the tasks ahead of the weekly plan. This gives the planning predictability and helps when the weekly plan is agreed upon. The weekly plan is important to make sure every task is healthy. Statsbygg, the Urbygningen project, scheduled too many meetings. The approach wasted time when the plans had to be changed repeatedly. To make sure only healthy tasks is started in the project, this thesis proposes *a make ready plan*. The make ready plan in this thesis is similar to the weekly plan used in the Sjøtroll project. The Sjøtroll project team has experienced more control, and the subcontractors are more involved in the planning, due to of the weekly work plan. The proposition is that the make ready plan presented in this thesis, can have the same positive effect on the Ledaal Park project, as experienced with using similar plan in the case of the Sjøtroll project.

The PPC must, based on the cases considered, be looked upon as an underutilized helping tool. In the Frederikskaj project, the project manager considered use of the PPC as inaccurate, because the workers responded with inaccuracy to the tool, as explained above. On the other hand, the Sjøtroll project experienced an increase in number of tasks that are planned and finished. This can suggest that the subcontractors are better equipped for the tasks that are ready to start, because of good planning. It can also mean that the subcontractors worked more to the target for the week. Both alternatives suggests that the use of PPC has improved the planning in the Sjøtroll project. In this thesis, the proposed make ready plan, calculate the PPC automatically and the information is transferred to the PPC worksheet. The Excel worksheet makes it easy to calculate the PPC in the project, if the proposed make ready plan is utilized. For the Ledaal Park project, the PPC will help control the project progress.

Takt time was not successively used in any of the cases. The Ledaal Park project is planning to use a Takt plan in a later phase. Takt time seems to be one of the Lean tools that is hard to implement and to explain to the workers. Workers might not see the potential for working in a rhythm throughout the building process. The advantages of Takt time is that the workers will know when they will start in one zone, and after a given Takt the workers will move to the next. Dividing the construction into zones, makes the project more predictable. Such an effect is achieved when it is set which trade should work in each zone after an agreed upon plan. The plan is possible to make in an Excel worksheet, like the one provided for this thesis. Subcontractors know from previous work how much time they need for the task, and it is therefore simple to approximate the time workers need on each task in the project.

Use of *the constraints log* is different in all the cases considered. The Sjøtroll project makes a detailed report of the constraints, and use a Pareto chart to discover the constraints that occur most frequent in the project. The Sjøtroll project uses the log to analyse the problems further, in comparison to the other projects. The other cases use a constraint log to discover and sort out the constraints. In these last cases, there is no effort made to look further into how the constraints occur and what is the better remedy either to avoid or evade such constraints in future project. The Sjøtroll project team analysed constraints while the project was going on. Such an approach helps to improve the planning process during the project. Furthermore, such a practice will help in future projects. However, none of the cases use the method of *lessons learned,* by taking the time to go through the project to analyse once over, after they are completed. According to the theory, Lean is about improving by learning from the problems that occurs. The method consists of a practice to analyse incidents of constraint, to find the cause, and to remedy the defiance so that the problem does not happen again.

To get the benefit of lessons learned, the project team should take time to evaluate the project with the aim to improve for the next project. The constraint log created for this thesis is connected to the information for the task contained in the Lean plan. By making this connection the process of writing the constraint log is simplified. When a constraint occurs in a task the Lean plan is marked, and the task information will be transfered to the constraint log. In the constraint log, it becomes easier just to mark the reasons for constraint without the need to supply the data for the task. In the same fashion the connection provides for the Pareto chart to give the information on which reason for constraint that occurs the most frequent. The Excel worksheet and connections made are explained in detail above in section 6.3.

In two of the cases the project hired an external consultant to help out with the implementation of Lean. This is the cases of Urbygningen and Sjøtroll. In the Urbygningen project, help from an external consultant was in demand when the management realized that implementation of Lean was challenging. As stated above, the consultant caused more problems than improvements to the Urbygningen project. In the other case, the Sjøtroll project, the external consultant made the transition to Lean tools smoother. Bringing in an external consultant helped the project team to better understand the tools in Lean and Last Planner System. The difference in the two projects, might be that the Urbygningen project brought in the external consultant to late in the process. While the Sjøtroll project on the other hand started up using the Lean tools in cooperation with the consultant. What work the external consultant did is not further explained in either of these cases.

Further comments

It seems that the construction industry might be less open minded about change than other industries. The cases explained in this thesis point to such an opinion. In Urbygningen and Ledaal Park the subcontractors had to take part in a Lean method course. Even so, both projects still have problems with the implementation of Lean. In the Urbygningen project, there were too many obstacles with the rehabilitation as such. With the new planning system the problems worsened. In the Ledaal Park project, the struggle is to set up a functional pull system. Even though the participants in the project has the knowledge of the Lean theory, the attitude seems to be that planning is easier done the way the participants are used to. In the Urbygningen project, the solution to occurring problems was to do planning by tradition. Similarly, the Ledaal Park project found it feasible to use a combination of the push and the pull system to meet with deadlines of the project.

As mentioned above the Urbygningen project used BIM stations. Lean and BIM complements each other by discovering constraint early. A 3D drawing and a video animation improves communication of the building, to the customers and to the subcontractors. Further development in BIM technology is in the interest of Lean used in the industry of construction. Information about the construction in rehabilitation projects will be easier to compute when one collects all the information concerning the process into one BIM model.

In this thesis the author has used Lean and Last Planner System in a BIM program, Synchro software. The software helps connect IFC files in the project to the project schedule. The author made a video animation by connecting the resources in Synchro software to the task. The video animation makes a visualized image of the schedule and the process of construction. The software helps both workers finding constraints in the plan, and the contractor can show the customer the construction process. The model also makes it easy to find information about the building. The Synchro software contains the necessary tools to make a longer look ahead plan and a weekly plan from the Gantt chart. Use of computer programs like the Synchro software reduces time spent on making the different plans separately, as many of the projects does.

There are many vendors of software offering products to the construction industry. However, it is not easy to connect or share files between the different software available. For the construction industry to utilize technology, the software offered must be open and compatible to share files with other vendors of software applications. One company should be able to use one software and share files with another company, also the ones using a software from other vendors.

The Lean method consists of many tools. Some of the tools are more independent, and others are dependent on each other. The master plan and the phase plan are dependent on each other. A master plan is of limited use on its own, but is a requisite to make the phases in a project. The look ahead plan, and the make ready plan are both tools that can be used separately. However, the look ahead plan and the make ready plan is more useful when used together with the phase plan. The look ahead plan contains the task for a number of weeks ahead. During the planning, constraints are discovered. When it is time to plan the make ready plan, some constraints are already discovered and fixed in the look ahead plan. Consequently, the tasks constraints are considered twice. This simplifies the work with the make ready plan.

PPC can be calculated independently, or it can be made dependent on the make ready plan. In the proposed PPC, Excel worksheet in this thesis, the PPC is dependent on the make ready plan worksheet. Connecting the make ready plan and the PPC will simplify the work in total. This is because the Excel worksheet will do the calculations as explained earlier.

Takt time is an independent tool. Project managers who decide on the rhythm in a project will be the users of Takt time.

A constraint log can be performed independently, or it may not. In the proposed solution described in this thesis, the constraint log is dependent. In the proposition it is connected to the Lean plan and the Pareto chart. Such a connection is a useful way to make the most out of the advantages of an Excel worksheet, because input data only needs to be put in once. The proposition worksheet in this thesis contains and simplifies the work of the constraint log with the Pareto chart.

From the assumptions made above, introduction of Lean tools should be done in an orderly and a considered manner. It is not necessary to make use of everything at once. An incremental approach seems to be the better answer. However, some of the tools go together or give benefit to one another. Some of the tools can be useful in an early-scaled adaption. Other tools are of better use in a full scale. In some cases, the better approach will be to introduce a tool where there is experience and understanding of Lean methodology by all or major part of the participants.

In the introduction of this thesis, there is a reference to research presented by SSB comparing the construction industry with other industries on the mainland Norway. The comparison shows that other industries have increased productivity, while the construction industry has a decreasing productivity. The work done in this thesis shows that the technology tools are available, there are actors in the business with knowledge of Lean methods, data is digital and can be computed. Even so, the technology, the knowledge and the data are not utilized to their full capacity.

This thesis demonstrates that collecting all documents in one worksheet and utilize the connections in the worksheets saves time. Such an approach will help the project team keep track of the documents and use the information more extensively. It is hard to tell why the tools, such as Excel, are not used to their full capacity. One reason might be that it takes time to set up the draft document. However, this is time saved in later projects. The same document can be used over again and will be an investment to the business.

In the future construction industry will be more dependent on the use of information technology. As shown with the use of the Excel worksheet and the Synchro software. Such use of software simplifies the planning process, reduce wasted time, and is important to increase productivity.

Conclusion

The cases investigated show that the use of Lean construction is in a start phase in the Norwegian construction industry. Backe Rogaland AS use some of the Lean methods in the Ledaal Park project. The use of Lean plan includes a master plan and phase plan. Pull plan is still not properly utilized in the project. It seems a fair assumption that the project would benefit from and improve by using Lean as done in the Excel worksheet proposed in this thesis.

Additional improvements in the planning process of the Ledaal Park project is to use the make ready plan with a PPC. Such an approach would help the project to start only the tasks that are healthy, and to keep track of which tasks that are finished on time.

Utilizing the constraint log and Pareto chart will help the project teams in Backe Rogaland AS to discover most reasons for constraint. The Pareto chart visualize the reasons for constraints, which helps Backe Rogaland AS target the reason and resolve the constraints.

Using BIM will help the project team in the planning process, and when communicating with the customers and the subcontractors. BIM is also useful to discover constraints in the drawings before the project begins. To make the most use of input data, it should be noted what software's have open format. By using programs with open format, the project will avoid compatibility issues in new projects.

For successfully implementation of the Last Planner System, the project should gradually implement Lean tools. Upgrading will be possible when the participants in the project are comfortable utilizing the tools applied.

Information technology can simplify the planning process and increase productivity. To keep up, Backe Rogaland AS must also utilize the tools available. The technology available can change the productivity in the construction industry, and such changes will make the market more disrupt.

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Appendix A

Effective Implementation of Last Planner System® in Construction Projects: A Case Study

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Abstract - **Construction industry has been relatively less productive compared to the manufacturing and process industry. Significant amount of construction projects have been delayed and/or exceeded the originally estimated budget. Planning has been a significant challenge in the construction industry due to highly customized nature of designs, construction process, suppliers as well as challenges involved in sub-contractors and suppliers. Planning, monitoring and continuous control of the progress of a construction project is vital to improve the projects' performance. Although the Lean construction approaches (LCAs) and Last Planner System® (LPS) have been proven to deliver target project performance in certain construction projects, to date, most of the engineering contractors struggle to implement them in practice. This manuscript presents the results of an illustrative case study that has been carried out in collaboration with a construction firm. The case study has been carried out to investigate the potential use of LCAs with special focus on the use of LPS in practice. Microsoft Excel and Synchro software have been used to deploy the LPS. The findings demonstrate how the planning capabilities have been improved with the support of plan percent completion (PPC) calculation done with the Microsoft Excel together with animation capabilities in Synchro software.**

Keywords – **Last planner system, Lean construction approach, building information modelling,**

I. INTRODUCTION

Lean thinking started in the Toyota production factory to improve quality and productivity. They found an easier and a faster way of mass-producing vehicles. Focusing on the sources of waste and flow, they continuously improved their product. Problems were found early in the production systems, therefor there were never any defects when the product was complete [1]. Over the years many industries have adopted Lean thinking to improve productivity. For instance, construction industry discusses about Lean construction which refer to how the Lean methods can be used in the construction industry. In Norway a few companies have started implementing Lean into their construction projects. In construction, Lean thinking can help find the source of wasted resources as human potential, material waste and time.

The Last Planner System ® (LPS) was first introduced by Glenn Ballard in 1993. Moreover, it is a planning, monitoring and control system that follows Lean construction principals [2]. The last planner is the person responsible for the work done in one section of the production (i.e. could be the person responsible for the electrical system) and LPS has four mechanism. They are what should be done, what can be done, what will be done and what did get done as shown in Fig. 1.

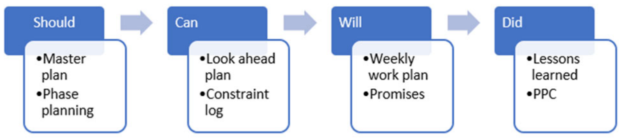

Fig. 1 LPS structure

There have been extensively of research on Building Information Modeling (BIM) and Lean construction separately. BIM and Lean constructions are independent process. However, since both are advancing technology to help the construction industry to improve. Then, there should be some correlation between the two processes. Moreover, BIM helps to reduce variables and constraints affect the design process and cycle time, these can be considered as Lean principals [3]. In addition, there are various BIM based software developed for simulating the construction sequence/scheduling. For instance, Synchro is a 4D BIM (i.e. 4th Dimension includes scheduling) and Virtual Design and Construction (VDC) software platform [40] which can be used such purposes. Hence, LPS can be implemented by collaborating with 4D BIM software which enable to improve productivity.

This paper discusses a case study of a construction project in Norway which investigates the use of Lean methods in project planning phase. The projects consist of two buildings, one rehabilitation and one new building. The project managers are using Lean methods to increase productivity. Furthermore, it also discusses to what extend the lean thinking implemented in the project and proposes improvements for the current practices.

II. PROBLEM BACKGROUND

Research done by SSB (Statistics Norway) shows that the industries in Norway have had a 30 percent increase in productivity, while the construction industry has fallen with 10 percent [4]. Fig. 2 shows the development in productivity of the construction industry compared to the other industries on mainland Norway from 2000 to 2016. This indicates that there is a need to carry out research on why the productivity of construction industry has such fall and how to uplift the productivity using the existing knowledge. There are various researches discussed in literature that implementation of lean thinking could be helpful to uplift the productivity [5]. Hence, in order to improve the productivity in the construction industry, the construction industry should change its traditional practices. Moreover, Norwegian construction industry has been trying to use different lean tools in their construction projects. However, it could be seen that it is still a challenge for them to implement the lean tools (i.e. LPS) effectively. Therefore, to understand how Lean is used in the construction industry, a case study is preformed, and this case study will examine how far a Norwegian company have come and propose future improvements.

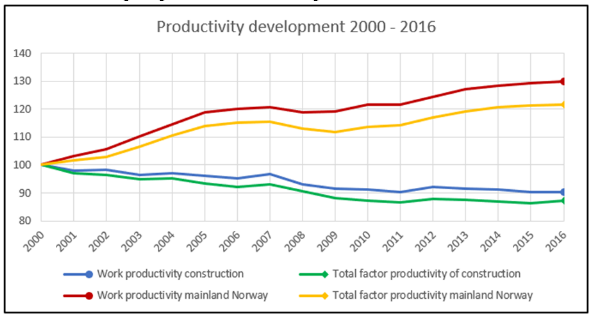

Fig. 2 Productivity development

III. METODODOLOGY

A qualitative research method is chosen to understand and analyze the case study. Because the subject in this case is a small-scale study and the researcher is involved in the project. Triangulation is used for the report to overcome weaknesses in some of the chosen methods. The following methods were used:

- Case study — Empirical data is gathered to understand the case and to develop an understanding of how the company performs.
- Unstructured interviews — Flexible and open for the interviewer to ask supplementary questions, helping the interviewer to get to the depth of the case.
- Non-participant observation — Observed meetings to understand the current planning process.
- Document study — Support observation and understand the early panning process.
- Digital tools — Excel and Synchro is used to simplify the planning process.

IV. CURRENT SITUATION

Backe Rogaland AS is part of the Backe group, which is one of Norway's 10 biggest construction contractors in 2017 [6]. Backe has been implementing Lean in all their projects to improve how they execute a project. At the Ledaal Park project consists of two buildings, one rehabilitation and one new building. In this project, the master- and phase schedule is included on the same document sheet, which is named as the Lean plan. The master plan included the start date and the final delivery of the project. The milestones have been revised through the project as contractors have been added to the project and as the customers have change their mind. Because the project is in an early phase, the look ahead plan is not used. In the beginning of the project, company only uses the detailed Lean plan. When the project starts with the takt plan, the project will try to use 3 weeks look ahead plan. Other documents used are a duration matrix to find the takt plan for the projects, a sheet explaining the zones and activities in each phase of the project and a flow chart of the tasks.

Ledaal Park project uses both push and pull planning in the project. A pull plan was developed at the project's starting point. However, a combined push and pull plan was later created in order to meet the promised delivery date. The plan calculates what needs to be done and how much it is needed to push the work from their current place.

The project manager writes down constraints during the progress meeting. The constrains are divided into the responsible companies. Delays caused by the constraints are also in the document sheet. The project manager uses a excel sheet for describing the constraint that occurs in the project. New notations are marked in red. The project manager does not record the reason for constraint in a Pareto chart. The informant believed a Pareto chart would take up too much time to fill out during the meetings. The informant explains that some Backe projects use it by having the contractors write the information down on sticky notes during the meeting. Afterwards the project leader can gather the notes and transfer the information to the other documents. The problem with this is that information might be interpreted wrong or there is need for more information. Ledaal Park mark delays in the project in the Lean plan with red. Current status of the task is marked in the Lean plan and finished work is struck through.

The project controls how much have been done, by checking the economy. Every trade has a financial budget. If concrete have used 30 % of their budget, then 30 % of the concrete work should be done (i.e. 30 % of the budget is used, but only 20 % of the concrete work is done, the concrete is running over budget and should be investigated). Fig. 3 shows the current planning process in Backe Rogaland AS. The current status will start the planning process of the project. The project team use Excel to make a Lean plan and a Takt plan. The project team will then move on to the next project with the same planning process as before. Though, the project managers users LPS, it can be seen that delaying projects due to lack of communication, lack of update of design changes, technical difficulties in excavation of soil and poor exchange of information.

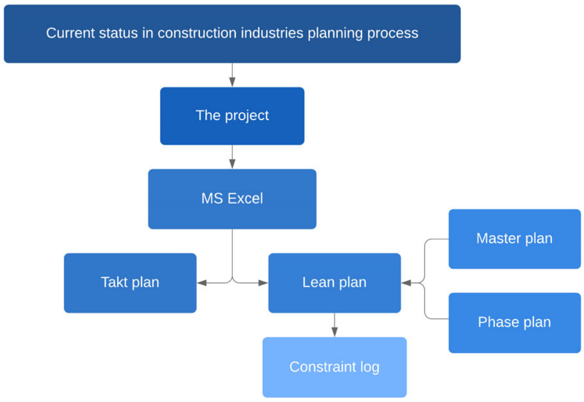

Fig. 3 Flow chart of current situation

V. SUGGESTED IMPOVMENTS

The project leader wants the meetings to run efficient, using many different Microsoft Excel (Excel) documents that does not work together is a waste of time. Collecting all these excel documents into one, makes it is easier to stay updated on the development in the project. The document can be shared with an internet link. This way any updates are easily shared with everyone in the project. The document contains a Lean plan, takt plan, look ahead plan, constraint log and percent plan complete (PPC). The sheets are connected making it easy to plan the project. If a task has a constraint it can be marked with a "x" in the Lean plan columns. The reason for the constraints can be marked with an "x". In the sheet for the pareto chart, each reason for constraint is counted and displayed in a diagram. The diagram gives an indication for what reason for constraint occurs the most times in the project.

The Lean plan is redesigned for the project. Today's date will change depending on the date. The project timeline dates are depending on the task's dates in the project and will change when they are changed. The earliest task given will also be the projects start date, and the latest task is the end of the project. The phase dates will change according to the task in the phases. The tasks in one phase are grouped together to make it easier to look at one phase. When a task is given a start and finish date the calendar will mark the original plan dark blue with number 2. The actual dates, if they are different from the original plan, will be lighter blue and with number 1 in the cell. Status of the task can be change between: Not started, On track, Delayed, Finished.

The takt plan template is used to find the takt time in the project. Contractor tells how many labour hours each task will take. The bar chart gives a visual image of the labour days. Seeing the average labour days, helps the planner finding the takt time. The make ready plan is filed out by the person responsible in the company. The person responsible for the tasks is given in the information box. In the checklist the person will mark with their initials the condition that prevents the task from being ready. When a cell is marked with initials, the ready column will automatically change from yes to no. In the ready column and the finished column, a cell will change colure if it is yes or no (i.e. Green means 'yes' and red means 'no'). This will visualize more clearly if tasks are healthy to start or not.

PPC is calculated from the number of finished tasks divided by the number of planed tasks for each contractor

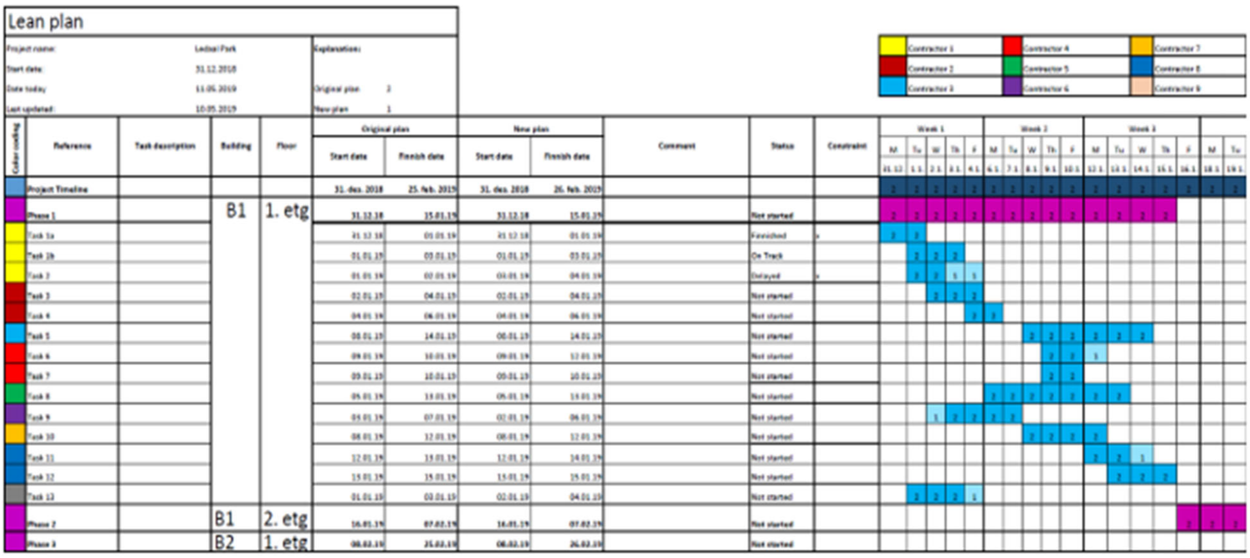

Fig. 4 Lean Plan

column, constraint. When a task is marked the task will automaticially be transferd to the constraint log. In the constraint log, reasons for constraints are devided into in the make work ready plan. An average PPC is calculated and visualized in a diagram (Fig. 5).

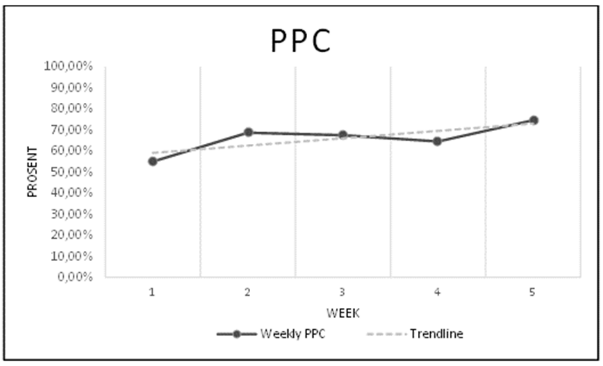

Fig. 5 PPC diagram

Synchro software is a computer program, which is made to improve the construction industry. It is a Building Information Model (BIM) software platform [7]. The software is a connection for programs that can export IFC files. Connecting drawings from the various of components in a building, the software will make a model of a project. The components can be connected to the tasks set in the Gantt chart. This can be used to visualize the construction sequence.

Synchro project planning gives more information on the project (see Fig. 6). The columns can be customized depending on what is needed of information. If task is delayed, it is easy to change the duration and see how the other task will be affected by the change.

Synchro has an option called task filters. Tasks can be showed depending on if they have started, finished or if there is need to look ahead in the schedule. A look ahead plan can either show planned task for one or two weeks ahead in the schedule of the chosen time. The critical path is also accessed here and will show the tasks that are in the critical path. Scheduling report will show a summary of the project and the tasks, how many tasks that are planned, in progress or complete. This can be used to make a PPC.

The Gantt chart can be customized with columns in Synchro. A make ready plan can be made in these columns, by adding a constraint in each column. The corresponding cell have a number for if the conditions are met for the task or not. If a task is ready, all constraints will have the number 1 and the task can be started. See Fig. 7 underneath for an example.

1. Information	2. Material	3. Crew	4. Equipment	5. Space	6. External Co...
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	0	1	1	1	1
1	1	1	0	1	1

Fig. 7 Make ready plan

Synchro can make a video animation of the construction. For the video to be made elements in the building must be connected to the corresponding task. Meaning that a slab in the first floor is connected to the task where the slab is made. When all the elements in the construction is connected to a task, the video is made. The video will follow the schedule of the tasks and the elements connected to the task will appear. At the start of the video only the elements that are not attached to a task is shown, as landscape and surrounding buildings. A video animation will help the workers see which task prevents another task from starting. The video animation made for Ledaal Park project is shown in a picture collage in Fig. 8. Fig. 9 shows a flow chart of the improved planning process. The current status of the planning process will begin the project. Then, the project team can decide to use Excel and/or Synchro. The different plans and tools are described earlier in the chapter. After the project is finished the project team should go over what they learned in the project. The lessons learned will find solutions for problems the team have had. The solutions will improve the status in the planning process and be used in future projects.

ID	Name	Duration	Start	Finish	3D ...	% Complete
T00560	Vegger 1 etg	5d	09:00 04.10....	17:00 10.10....	29	0.00
T00570	Dekke 1 etg	10d	09:00 10.10....	17:00 23.10....	14	0.00
T00580	Vegger 2 etg	5d	09:00 24.10....	17:00 30.10....	27	0.00
T00590	Dekke 2 etg	10d	09:00 30.10....	17:00 12.11....	14	0.00
T00610	Vegger 3 etg	5d	09:00 13.11....	17:00 19.11....	27	0.00
T00760	Dekke 3 etg	10d	09:00 19.11....	17:00 02.12....	14	0.00
T00770	Vegger 4 etg	5d	09:00 03.12....	17:00 09.12....	27	0.00
T00780	Dekke 4 etg	10d	09:00 09.12....	17:00 20.12....	1	0.00
T00790	Tak vegger	1d	09:00 20.12....	17:00 20.12....	4	0.00

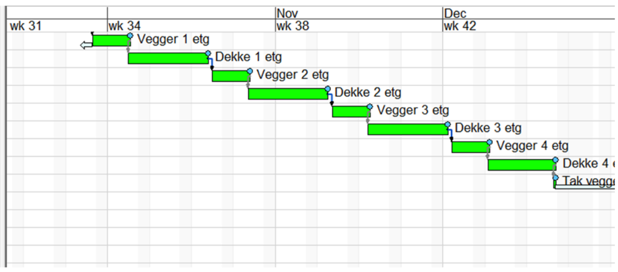

Fig. 6 Gantt chart with schedule

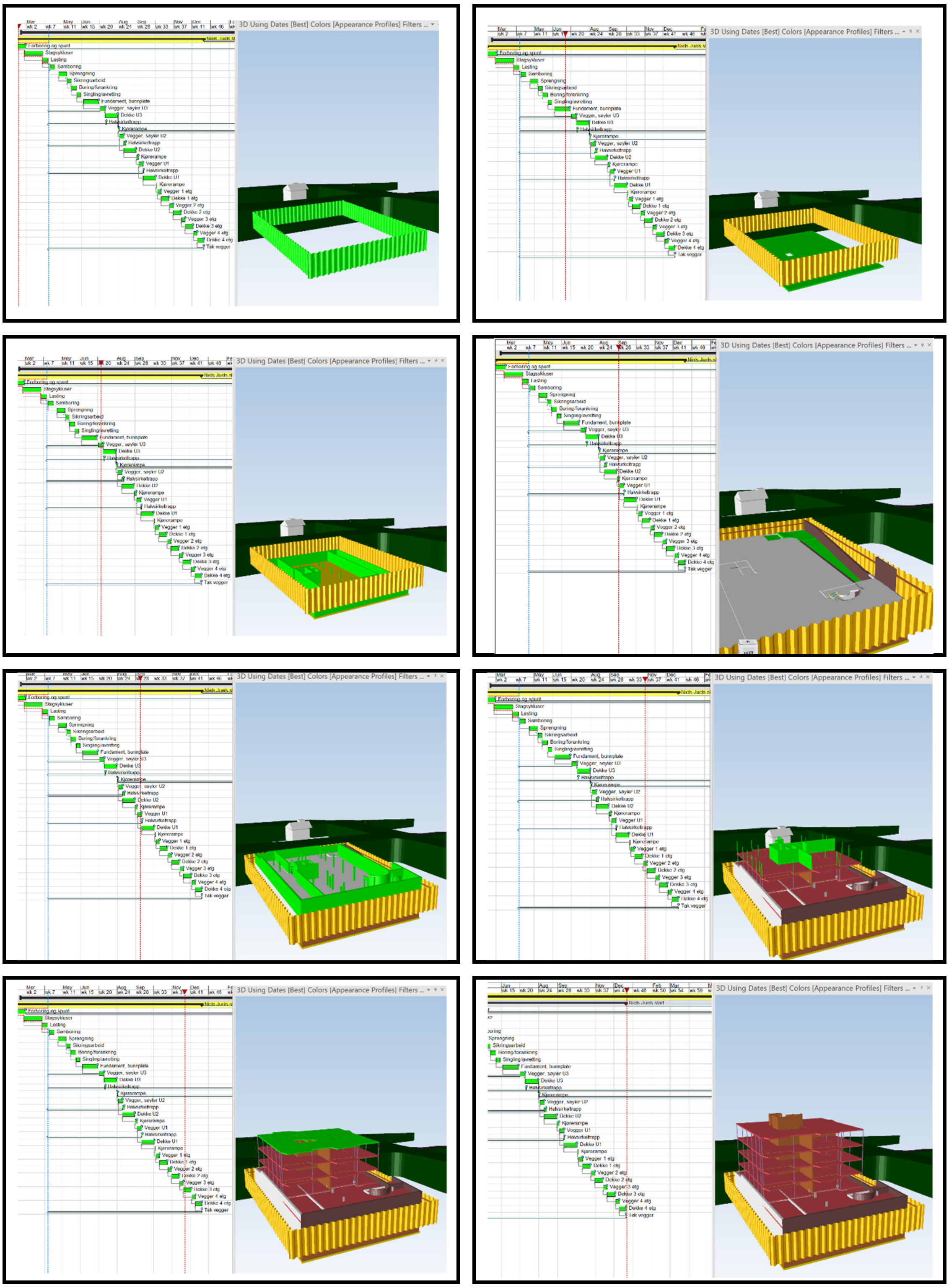

Fig. 8 Video animation in Synchro

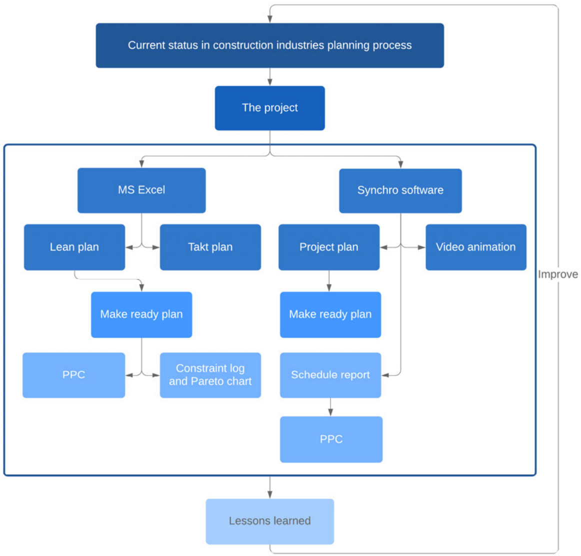

Fig. 9 Flow chart of suggested improvements

VI. CONCLUSION

In the Lean plan made by the company it is harder to change the start and finish dates of the task compared to the improved Lean plan. The improved Lean plan highlights the master plan and divides the task into phases, making the plan clear and easy to adjust. The improved excel document have gathered the different sheets the company use and included a PPC, Pareto chart and make ready plan. Having it all together will improve communication between the documents and help the users stay updated on the plan. To further improve the productivity in the company, it is important that the project team learn from their problems. The updated constraint log with reasons will help to understand which problems are the most occurring. If the project team find the causes of the problems, solutions can be found to avoid making the same mistake again. To find the problem both the PPC and the Pareto chart can be used.

Synchro helps to visualize the project plan for both the contractors, subcontractors and customer. Problems can be detected early and avoided by looking at the model and see if planed task can go as planned. The software can make a look ahead plan with the decided number of weeks. Adding the make ready columns to the schedule makes it easy to make task ready and healthy to perform.

Productivity in the planning process will improve with better communication through Excel and use of BIM software's such as Synchro.

VII. ACKNOWLOGMENT

The authors would like to thank Backe Rogaland AS. Backe Rogaland AS has supported the research with information and made the case study possible. Authors would like to give a specially thank you to Alisa Nilsen for sharing her time and knowledge.

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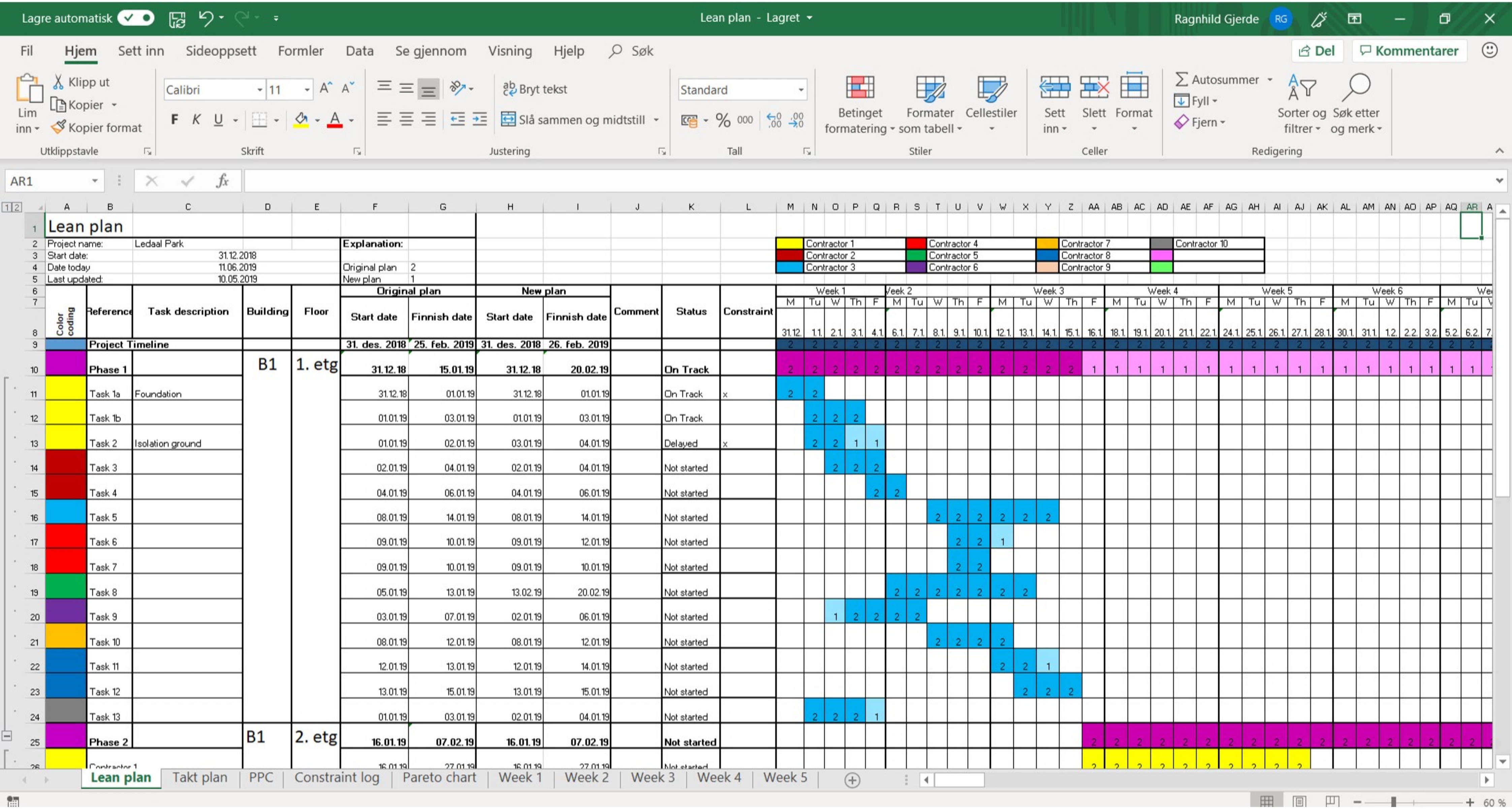
Appendix B

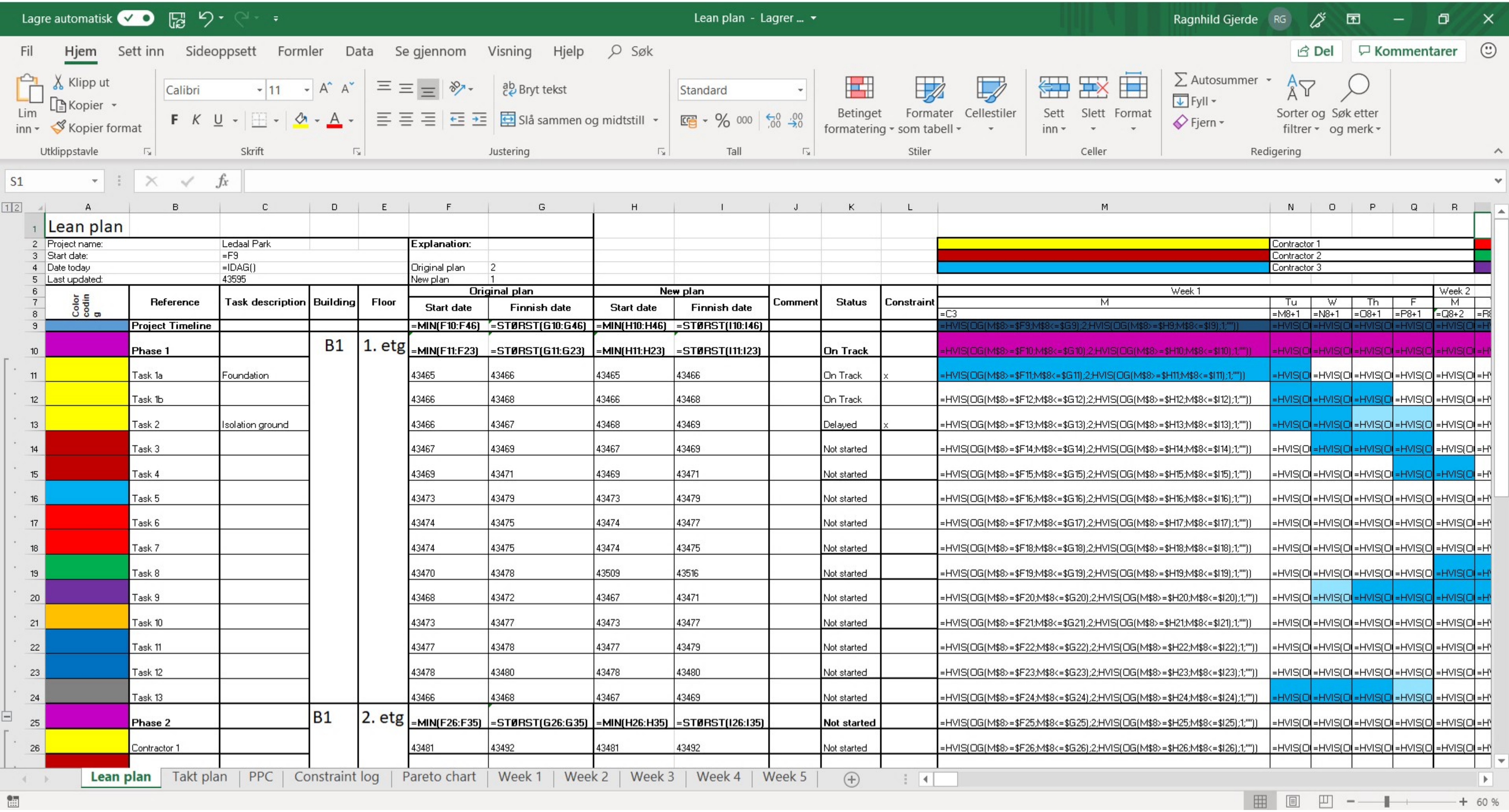


Lean plan										
Project name:	Ledaal Park			**Explanation:**						
Start date:	31.12.2018									
Date today	11.06.2019			Original plan	2					
Last updated:	10.05.2019			New plan	1					

Color coding	Reference	Task description	Building	Floor	Original plan: Start date	Original plan: Finnish date	New plan: Start date	New plan: Finnish date	Comment	Status	Constraint
	Project Timeline				**31. des. 2018**	**25. feb. 2019**	**31. des. 2018**	**26. feb. 2019**			
	Phase 1		B1	1. etg	**31.12.18**	**15.01.19**	**31.12.18**	**20.02.19**		**On Track**	
	Task 1a	Foundation			31.12.18	01.01.19	31.12.18	01.01.19		On Track	x
	Task 1b				01.01.19	03.01.19	01.01.19	03.01.19		On Track	
	Task 2	Isolation ground			01.01.19	02.01.19	03.01.19	04.01.19		Delayed	x
	Task 3				02.01.19	04.01.19	02.01.19	04.01.19		Not started	
	Task 4				04.01.19	06.01.19	04.01.19	06.01.19		Not started	
	Task 5				08.01.19	14.01.19	08.01.19	14.01.19		Not started	
	Task 6				09.01.19	10.01.19	09.01.19	12.01.19		Not started	
	Task 7				09.01.19	10.01.19	09.01.19	10.01.19		Not started	
	Task 8				05.01.19	13.01.19	13.02.19	20.02.19		Not started	
	Task 9				03.01.19	07.01.19	02.01.19	06.01.19		Not started	
	Task 10				08.01.19	12.01.19	08.01.19	12.01.19		Not started	
	Task 11				12.01.19	13.01.19	12.01.19	14.01.19		Not started	
	Task 12				13.01.19	15.01.19	13.01.19	15.01.19		Not started	
	Task 13				01.01.19	03.01.19	02.01.19	04.01.19		Not started	
	Phase 2		B1	2. etg	**16.01.19**	**07.02.19**	**16.01.19**	**07.02.19**		**Not started**	
	Contractor 1				16.01.19	27.01.19	16.01.19	27.01.19		Not started	

Contractor 1	Contractor 4	Contractor 7	Contractor 10
Contractor 2	Contractor 5	Contractor 8	
Contractor 3	Contractor 6	Contractor 9	

Lean plan | Takt plan | PPC | Constraint log | Pareto chart | Week 1 | Week 2 | Week 3 | Week 4 | Week 5

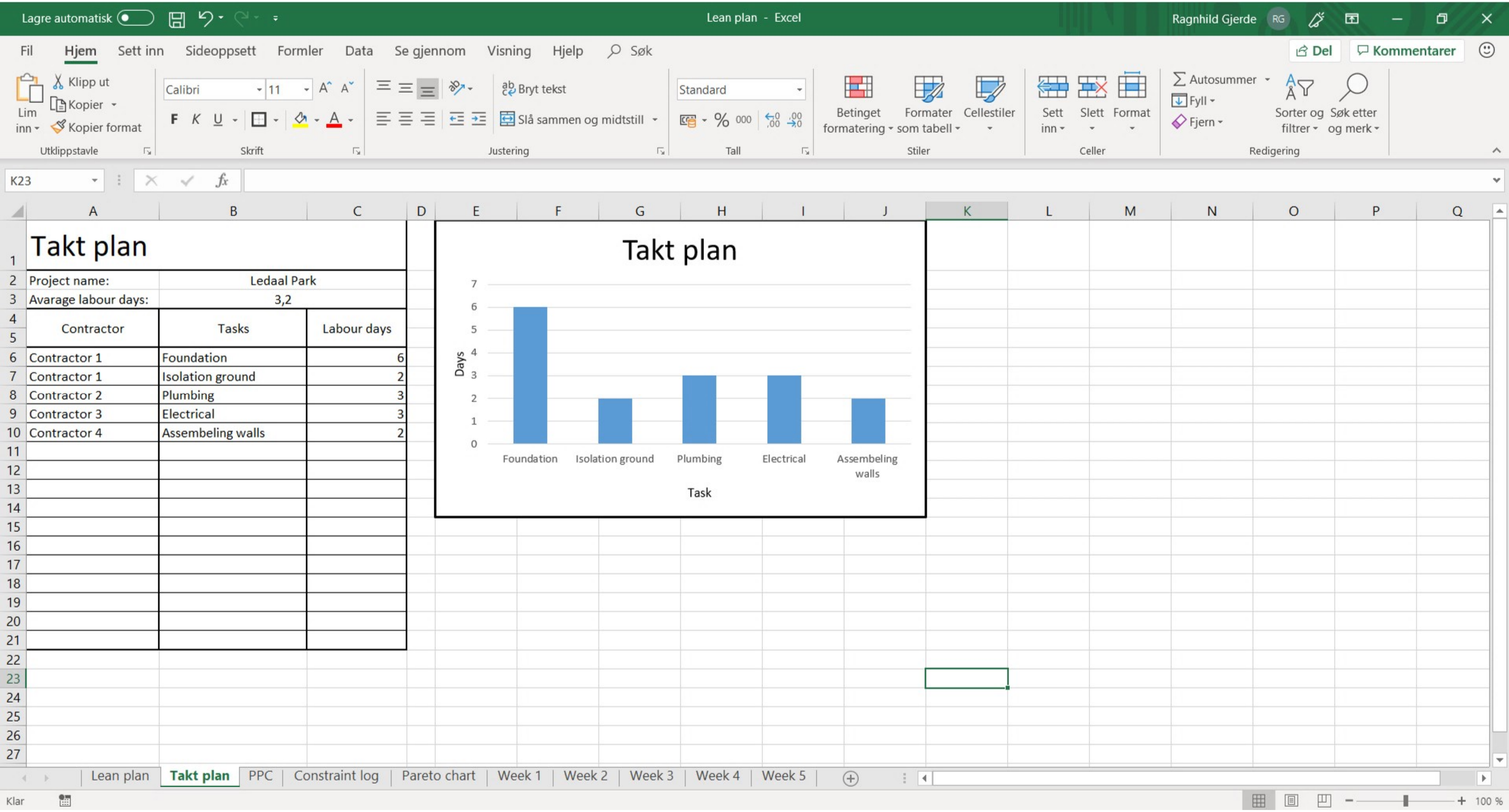


1	Lean plan	
2	Project name:	Ledaal Park
3	Start date:	=F9
4	Date today	=IDAG()
5	Last updated:	43595

Explanation:	
Original plan	2
New plan	1

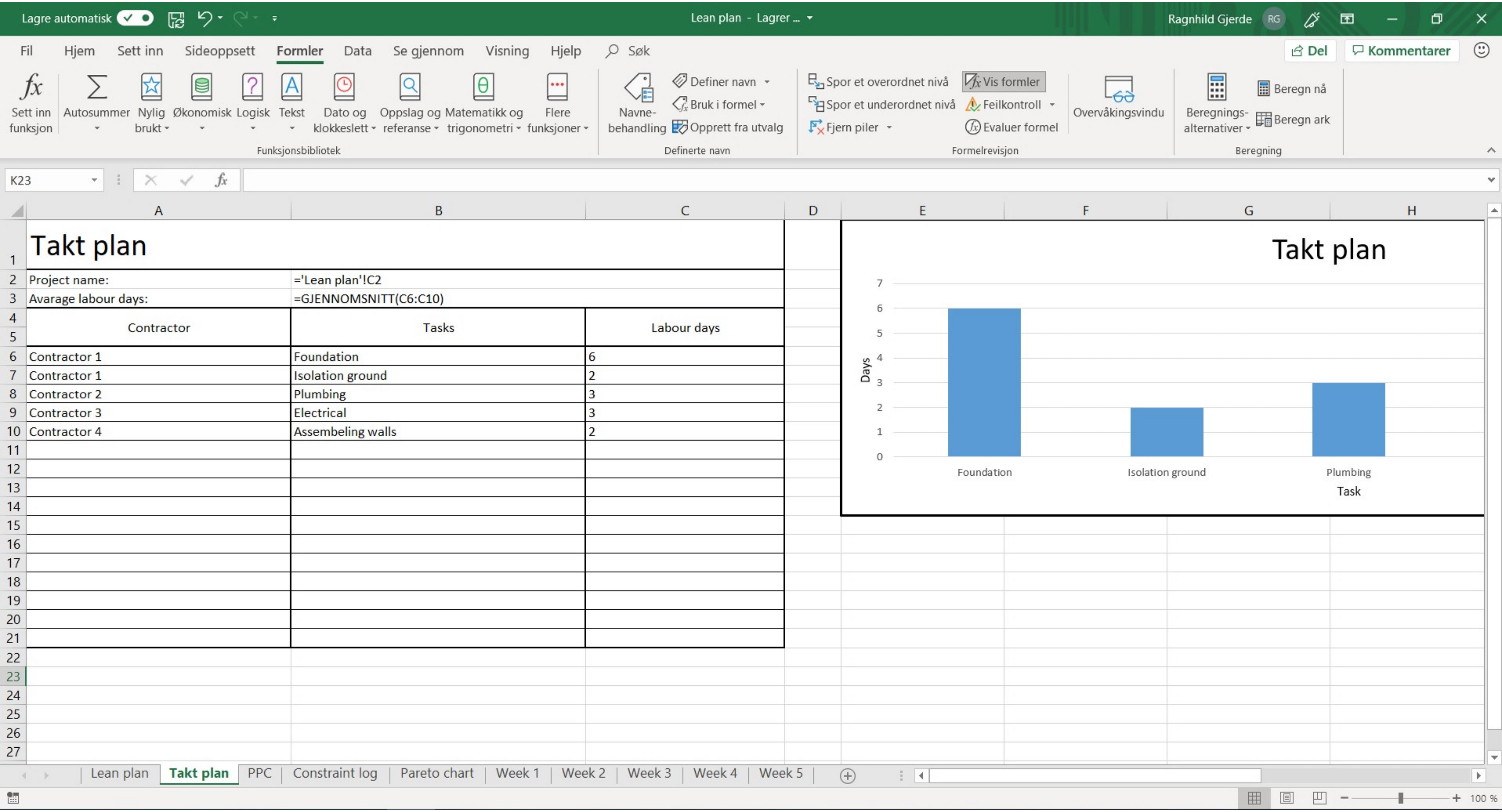
	Contractor 1
	Contractor 2
	Contractor 3

Row	Color coding	Reference	Task description	Building	Floor	Original plan: Start date	Original plan: Finnish date	New plan: Start date	New plan: Finnish date	Comment	Status	Constraint	Week 1: M	Tu	W	Th	F	Week 2: M	
8													=C3	=M8+1	=N8+1	=O8+1	=P8+1	=Q8+2	=R8
9		Project Timeline				=MIN(F10:F46)	=STØRST(G10:G46)	=MIN(H10:H46)	=STØRST(I10:I46)				=HVIS(OG(M$8>=$F9;M$8<=$G9);2;HVIS(OG(M$8>=$H9;M$8<=$I9);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
10		Phase 1		B1	1. etg	=MIN(F11:F23)	=STØRST(G11:G23)	=MIN(H11:H23)	=STØRST(I11:I23)		On Track		=HVIS(OG(M$8>=$F10;M$8<=$G10);2;HVIS(OG(M$8>=$H10;M$8<=$I10);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
11		Task 1a	Foundation			43465	43466	43465	43466		On Track	x	=HVIS(OG(M$8>=$F11;M$8<=$G11);2;HVIS(OG(M$8>=$H11;M$8<=$I11);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
12		Task 1b				43466	43468	43466	43468		On Track		=HVIS(OG(M$8>=$F12;M$8<=$G12);2;HVIS(OG(M$8>=$H12;M$8<=$I12);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
13		Task 2	Isolation ground			43466	43467	43468	43469		Delayed	x	=HVIS(OG(M$8>=$F13;M$8<=$G13);2;HVIS(OG(M$8>=$H13;M$8<=$I13);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
14		Task 3				43467	43469	43467	43469		Not started		=HVIS(OG(M$8>=$F14;M$8<=$G14);2;HVIS(OG(M$8>=$H14;M$8<=$I14);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
15		Task 4				43469	43471	43469	43471		Not started		=HVIS(OG(M$8>=$F15;M$8<=$G15);2;HVIS(OG(M$8>=$H15;M$8<=$I15);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
16		Task 5				43473	43479	43473	43479		Not started		=HVIS(OG(M$8>=$F16;M$8<=$G16);2;HVIS(OG(M$8>=$H16;M$8<=$I16);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
17		Task 6				43474	43475	43474	43477		Not started		=HVIS(OG(M$8>=$F17;M$8<=$G17);2;HVIS(OG(M$8>=$H17;M$8<=$I17);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
18		Task 7				43474	43475	43474	43475		Not started		=HVIS(OG(M$8>=$F18;M$8<=$G18);2;HVIS(OG(M$8>=$H18;M$8<=$I18);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
19		Task 8				43470	43478	43509	43516		Not started		=HVIS(OG(M$8>=$F19;M$8<=$G19);2;HVIS(OG(M$8>=$H19;M$8<=$I19);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
20		Task 9				43468	43472	43467	43471		Not started		=HVIS(OG(M$8>=$F20;M$8<=$G20);2;HVIS(OG(M$8>=$H20;M$8<=$I20);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
21		Task 10				43473	43477	43473	43477		Not started		=HVIS(OG(M$8>=$F21;M$8<=$G21);2;HVIS(OG(M$8>=$H21;M$8<=$I21);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
22		Task 11				43477	43478	43477	43479		Not started		=HVIS(OG(M$8>=$F22;M$8<=$G22);2;HVIS(OG(M$8>=$H22;M$8<=$I22);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
23		Task 12				43478	43480	43478	43480		Not started		=HVIS(OG(M$8>=$F23;M$8<=$G23);2;HVIS(OG(M$8>=$H23;M$8<=$I23);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
24		Task 13				43466	43468	43467	43469		Not started		=HVIS(OG(M$8>=$F24;M$8<=$G24);2;HVIS(OG(M$8>=$H24;M$8<=$I24);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
25		Phase 2		B1	2. etg	=MIN(F26:F35)	=STØRST(G26:G35)	=MIN(H26:H35)	=STØRST(I26:I35)		Not started		=HVIS(OG(M$8>=$F25;M$8<=$G25);2;HVIS(OG(M$8>=$H25;M$8<=$I25);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H
26		Contractor 1				43481	43492	43481	43492		Not started		=HVIS(OG(M$8>=$F26;M$8<=$G26);2;HVIS(OG(M$8>=$H26;M$8<=$I26);1;""))	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=HVIS(O	=H



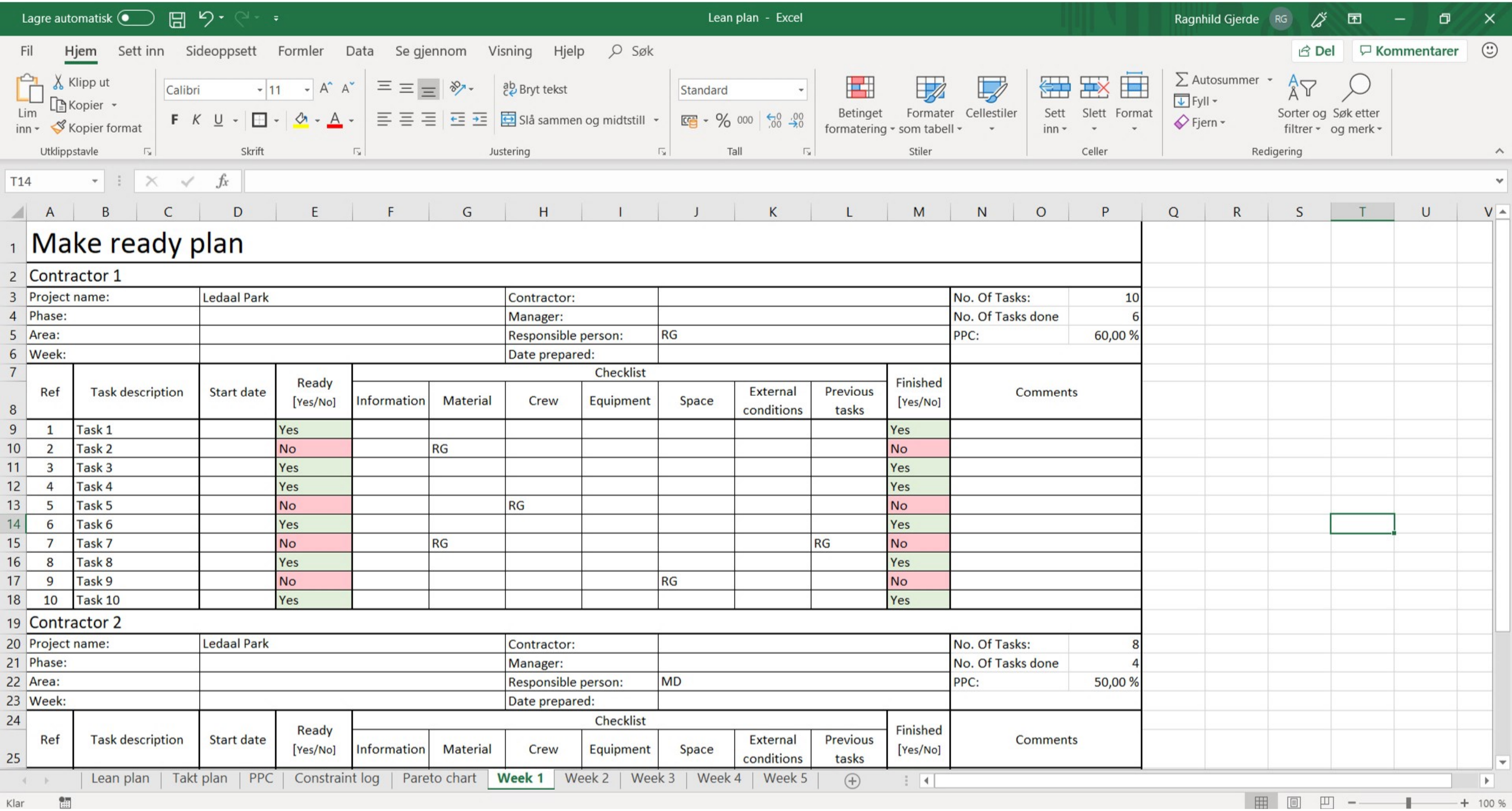
Takt plan

Project name:	Ledaal Park	
Avarage labour days:	3,2	
Contractor	Tasks	Labour days
Contractor 1	Foundation	6
Contractor 1	Isolation ground	2
Contractor 2	Plumbing	3
Contractor 3	Electrical	3
Contractor 4	Assembeling walls	2



Takt plan

Project name:	='Lean plan'!C2	
Avarage labour days:	=GJENNOMSNITT(C6:C10)	
Contractor	Tasks	Labour days
Contractor 1	Foundation	6
Contractor 1	Isolation ground	2
Contractor 2	Plumbing	3
Contractor 3	Electrical	3
Contractor 4	Assembeling walls	2



Make ready plan

Contractor 1

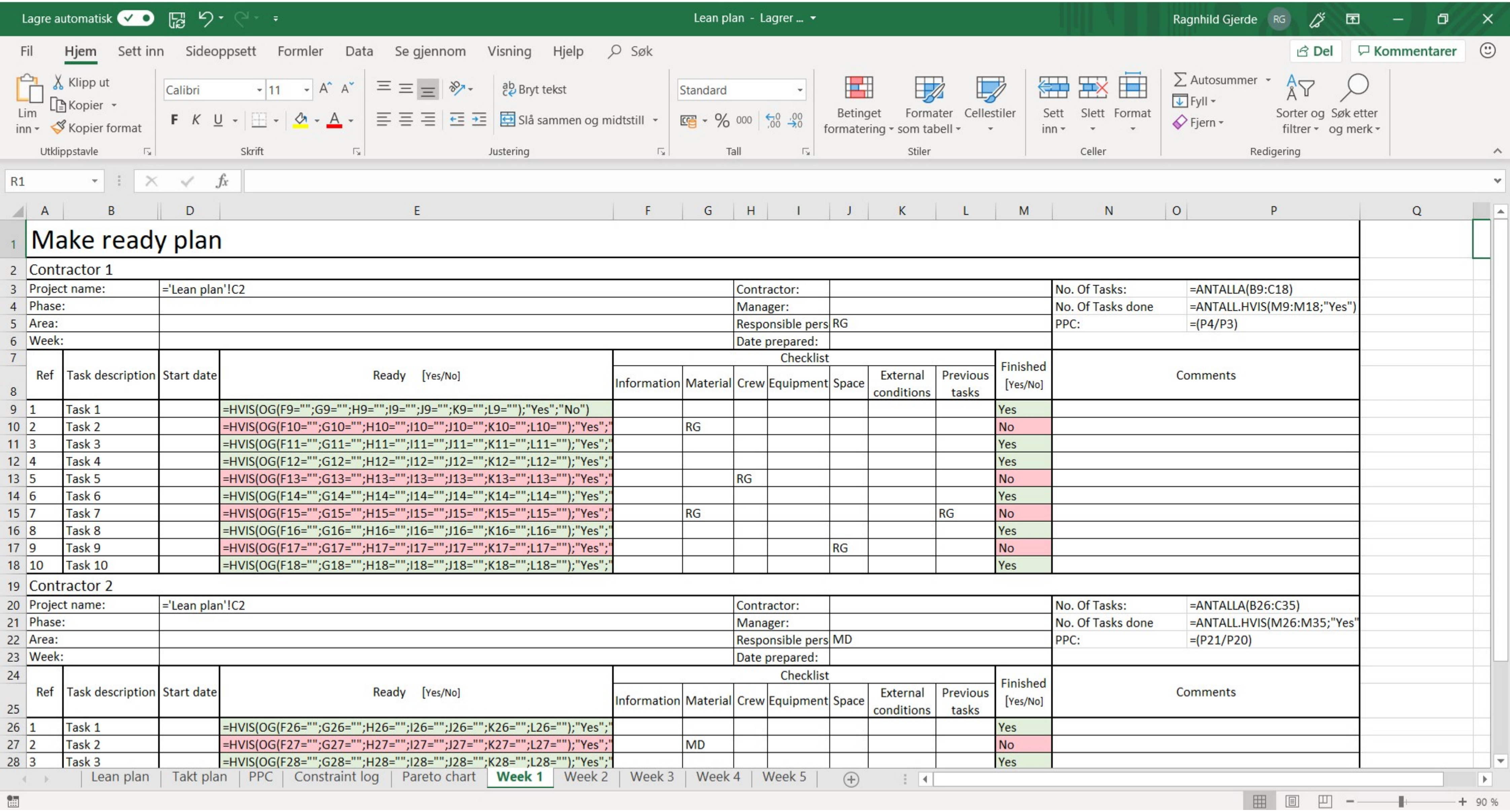
Project name:	Ledaal Park	Contractor:		No. Of Tasks:	10
Phase:		Manager:		No. Of Tasks done	6
Area:		Responsible person:	RG	PPC:	60,00 %
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments
1	Task 1		Yes								Yes	
2	Task 2		No		RG						No	
3	Task 3		Yes								Yes	
4	Task 4		Yes								Yes	
5	Task 5		No			RG					No	
6	Task 6		Yes								Yes	
7	Task 7		No		RG					RG	No	
8	Task 8		Yes								Yes	
9	Task 9		No					RG			No	
10	Task 10		Yes								Yes	

Contractor 2

Project name:	Ledaal Park	Contractor:		No. Of Tasks:	8
Phase:		Manager:		No. Of Tasks done	4
Area:		Responsible person:	MD	PPC:	50,00 %
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments



Make ready plan

Contractor 1

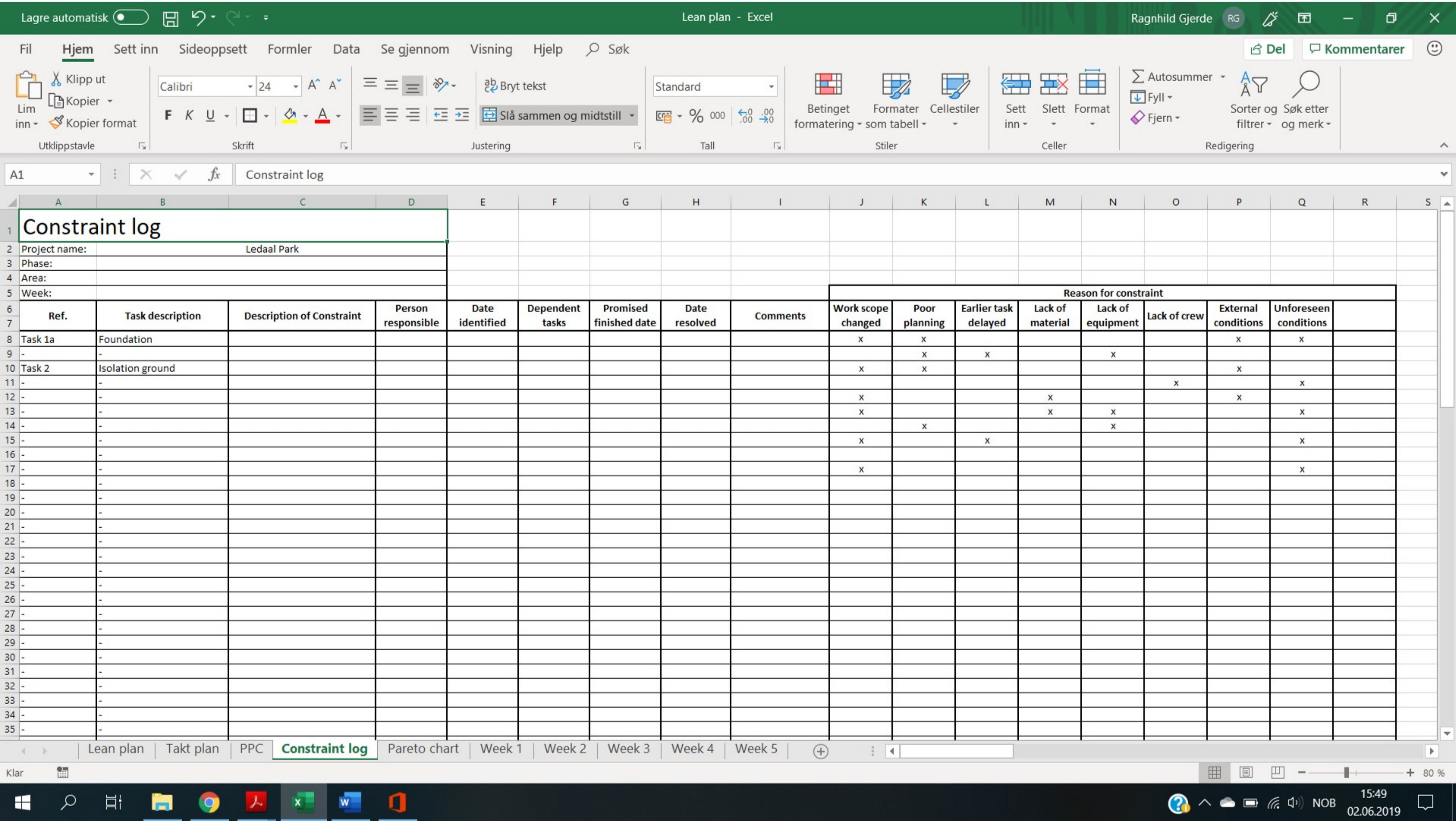
Project name:	='Lean plan'!C2	Contractor:		No. Of Tasks:	=ANTALLA(B9:C18)
Phase:		Manager:		No. Of Tasks done	=ANTALL.HVIS(M9:M18;"Yes")
Area:		Responsible pers	RG	PPC:	=(P4/P3)
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments
1	Task 1		=HVIS(OG(F9="";G9="";H9="";I9="";J9="";K9="";L9="");"Yes";"No")								Yes	
2	Task 2		=HVIS(OG(F10="";G10="";H10="";I10="";J10="";K10="";L10="");"Yes";"		RG						No	
3	Task 3		=HVIS(OG(F11="";G11="";H11="";I11="";J11="";K11="";L11="");"Yes";"								Yes	
4	Task 4		=HVIS(OG(F12="";G12="";H12="";I12="";J12="";K12="";L12="");"Yes";"								Yes	
5	Task 5		=HVIS(OG(F13="";G13="";H13="";I13="";J13="";K13="";L13="");"Yes";"			RG					No	
6	Task 6		=HVIS(OG(F14="";G14="";H14="";I14="";J14="";K14="";L14="");"Yes";"								Yes	
7	Task 7		=HVIS(OG(F15="";G15="";H15="";I15="";J15="";K15="";L15="");"Yes";"		RG					RG	No	
8	Task 8		=HVIS(OG(F16="";G16="";H16="";I16="";J16="";K16="";L16="");"Yes";"								Yes	
9	Task 9		=HVIS(OG(F17="";G17="";H17="";I17="";J17="";K17="";L17="");"Yes";"					RG			No	
10	Task 10		=HVIS(OG(F18="";G18="";H18="";I18="";J18="";K18="";L18="");"Yes";"								Yes	

Contractor 2

Project name:	='Lean plan'!C2	Contractor:		No. Of Tasks:	=ANTALLA(B26:C35)
Phase:		Manager:		No. Of Tasks done	=ANTALL.HVIS(M26:M35;"Yes"
Area:		Responsible pers	MD	PPC:	=(P21/P20)
Week:		Date prepared:			

Ref	Task description	Start date	Ready [Yes/No]	Checklist: Information	Material	Crew	Equipment	Space	External conditions	Previous tasks	Finished [Yes/No]	Comments
1	Task 1		=HVIS(OG(F26="";G26="";H26="";I26="";J26="";K26="";L26="");"Yes";"								Yes	
2	Task 2		=HVIS(OG(F27="";G27="";H27="";I27="";J27="";K27="";L27="");"Yes";"		MD						No	
3	Task 3		=HVIS(OG(F28="";G28="";H28="";I28="";J28="";K28="";L28="");"Yes";"								Yes	



Constraint log

Project name: Ledaal Park
Phase:
Area:
Week:

Ref.	Task description	Description of Constraint	Person responsible	Date identified	Dependent tasks	Promised finished date	Date resolved	Comments	Reason for constraint: Work scope changed	Poor planning	Earlier task delayed	Lack of material	Lack of equipment	Lack of crew	External conditions	Unforeseen conditions
Task 1a	Foundation								x	x					x	x
-	-									x	x		x			
Task 2	Isolation ground								x	x					x	
-	-													x		x
-	-								x			x			x	
-	-								x			x	x			x
-	-									x			x			
-	-								x		x					x
-	-															
-	-								x							x
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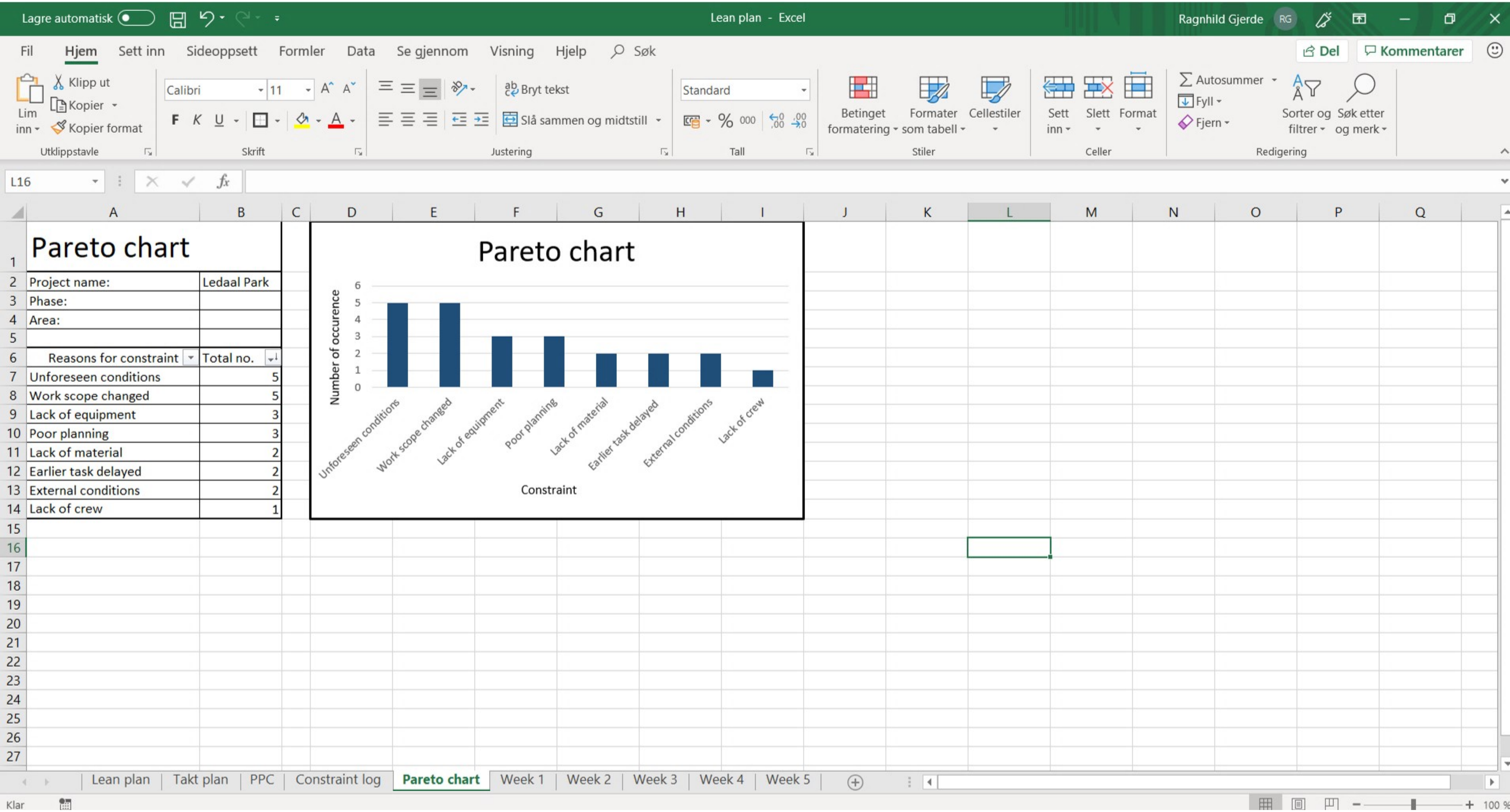
Constraint log

Project name:	='Lean plan'!C2
Phase:	
Area:	
Week:	

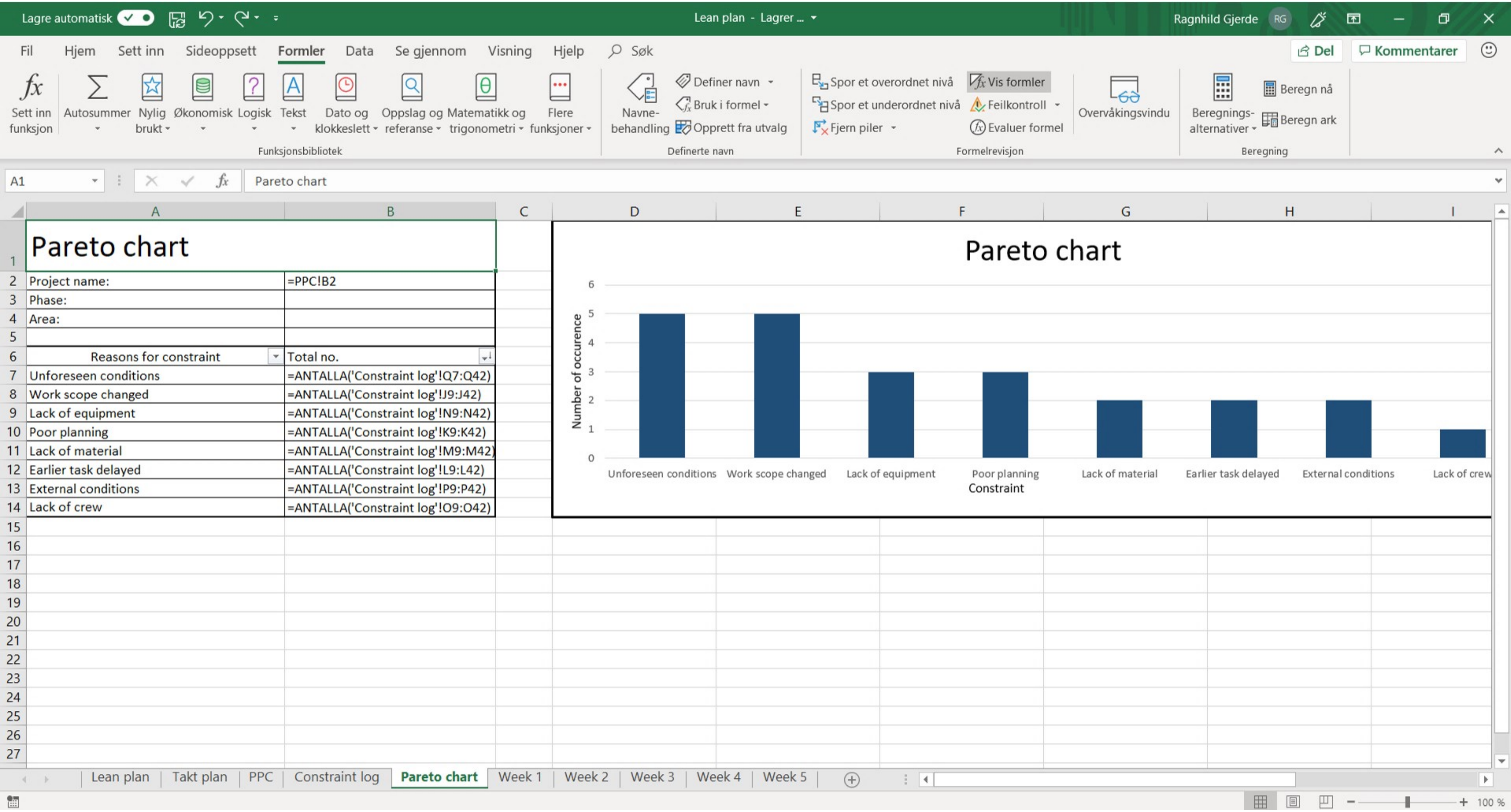
Ref.	Task description	Description of Constraint	Person responsible	Date identified	Dependent tasks	Promised finished date	Date resolved	Comments	Work scope changed	Poor planning	Earlier task delayed
=HVIS('Lean plan'!L11="x";'Lean plan'!B11;"-")	=HVIS('Lean plan'!L11="x";'Lean plan'!C11;"-")								x	x	
=HVIS('Lean plan'!L12="x";'Lean plan'!B12;"-")	=HVIS('Lean plan'!L12="x";'Lean plan'!C12;"-")									x	x
=HVIS('Lean plan'!L13="x";'Lean plan'!B13;"-")	=HVIS('Lean plan'!L13="x";'Lean plan'!C13;"-")								x	x	
=HVIS('Lean plan'!L14="x";'Lean plan'!B14;"-")	=HVIS('Lean plan'!L14="x";'Lean plan'!C14;"-")										
=HVIS('Lean plan'!L15="x";'Lean plan'!B15;"-")	=HVIS('Lean plan'!L15="x";'Lean plan'!C15;"-")								x		
=HVIS('Lean plan'!L16="x";'Lean plan'!B16;"-")	=HVIS('Lean plan'!L16="x";'Lean plan'!C16;"-")								x		
=HVIS('Lean plan'!L17="x";'Lean plan'!B17;"-")	=HVIS('Lean plan'!L17="x";'Lean plan'!C17;"-")									x	
=HVIS('Lean plan'!L18="x";'Lean plan'!B18;"-")	=HVIS('Lean plan'!L18="x";'Lean plan'!C18;"-")								x		x
=HVIS('Lean plan'!L19="x";'Lean plan'!B19;"-")	=HVIS('Lean plan'!L19="x";'Lean plan'!C19;"-")										
=HVIS('Lean plan'!L20="x";'Lean plan'!B20;"-")	=HVIS('Lean plan'!L20="x";'Lean plan'!C20;"-")								x		
=HVIS('Lean plan'!L21="x";'Lean plan'!B21;"-")	=HVIS('Lean plan'!L21="x";'Lean plan'!C21;"-")										
=HVIS('Lean plan'!L22="x";'Lean plan'!B22;"-")	=HVIS('Lean plan'!L22="x";'Lean plan'!C22;"-")										
=HVIS('Lean plan'!L23="x";'Lean plan'!B23;"-")	=HVIS('Lean plan'!L23="x";'Lean plan'!C23;"-")										
=HVIS('Lean plan'!L24="x";'Lean plan'!B24;"-")	=HVIS('Lean plan'!L24="x";'Lean plan'!C24;"-")										
=HVIS('Lean plan'!L25="x";'Lean plan'!B25;"-")	=HVIS('Lean plan'!L25="x";'Lean plan'!C25;"-")										
=HVIS('Lean plan'!L26="x";'Lean plan'!B26;"-")	=HVIS('Lean plan'!L26="x";'Lean plan'!C26;"-")										
=HVIS('Lean plan'!L27="x";'Lean plan'!B27;"-")	=HVIS('Lean plan'!L27="x";'Lean plan'!C27;"-")										
=HVIS('Lean plan'!L28="x";'Lean plan'!B28;"-")	=HVIS('Lean plan'!L28="x";'Lean plan'!C28;"-")										
=HVIS('Lean plan'!L29="x";'Lean plan'!B29;"-")	=HVIS('Lean plan'!L29="x";'Lean plan'!C29;"-")										
=HVIS('Lean plan'!L30="x";'Lean plan'!B30;"-")	=HVIS('Lean plan'!L30="x";'Lean plan'!C30;"-")										
=HVIS('Lean plan'!L31="x";'Lean plan'!B31;"-")	=HVIS('Lean plan'!L31="x";'Lean plan'!C31;"-")										
=HVIS('Lean plan'!L32="x";'Lean plan'!B32;"-")	=HVIS('Lean plan'!L32="x";'Lean plan'!C32;"-")										
=HVIS('Lean plan'!L33="x";'Lean plan'!B33;"-")	=HVIS('Lean plan'!L33="x";'Lean plan'!C33;"-")										
=HVIS('Lean plan'!L34="x";'Lean plan'!B34;"-")	=HVIS('Lean plan'!L34="x";'Lean plan'!C34;"-")										
=HVIS('Lean plan'!L35="x";'Lean plan'!B35;"-")	=HVIS('Lean plan'!L35="x";'Lean plan'!C35;"-")										
=HVIS('Lean plan'!L36="x";'Lean plan'!B36;"-")	=HVIS('Lean plan'!L36="x";'Lean plan'!C36;"-")										
=HVIS('Lean plan'!L37="x";'Lean plan'!B37;"-")	=HVIS('Lean plan'!L37="x";'Lean plan'!C37;"-")										
=HVIS('Lean plan'!L38="x";'Lean plan'!B38;"-")	=HVIS('Lean plan'!L38="x";'Lean plan'!C38;"-")										

Lean plan | Takt plan | PPC | Constraint log | Pareto chart | Week 1 | Week 2 | Week 3 | Week 4 | Week 5

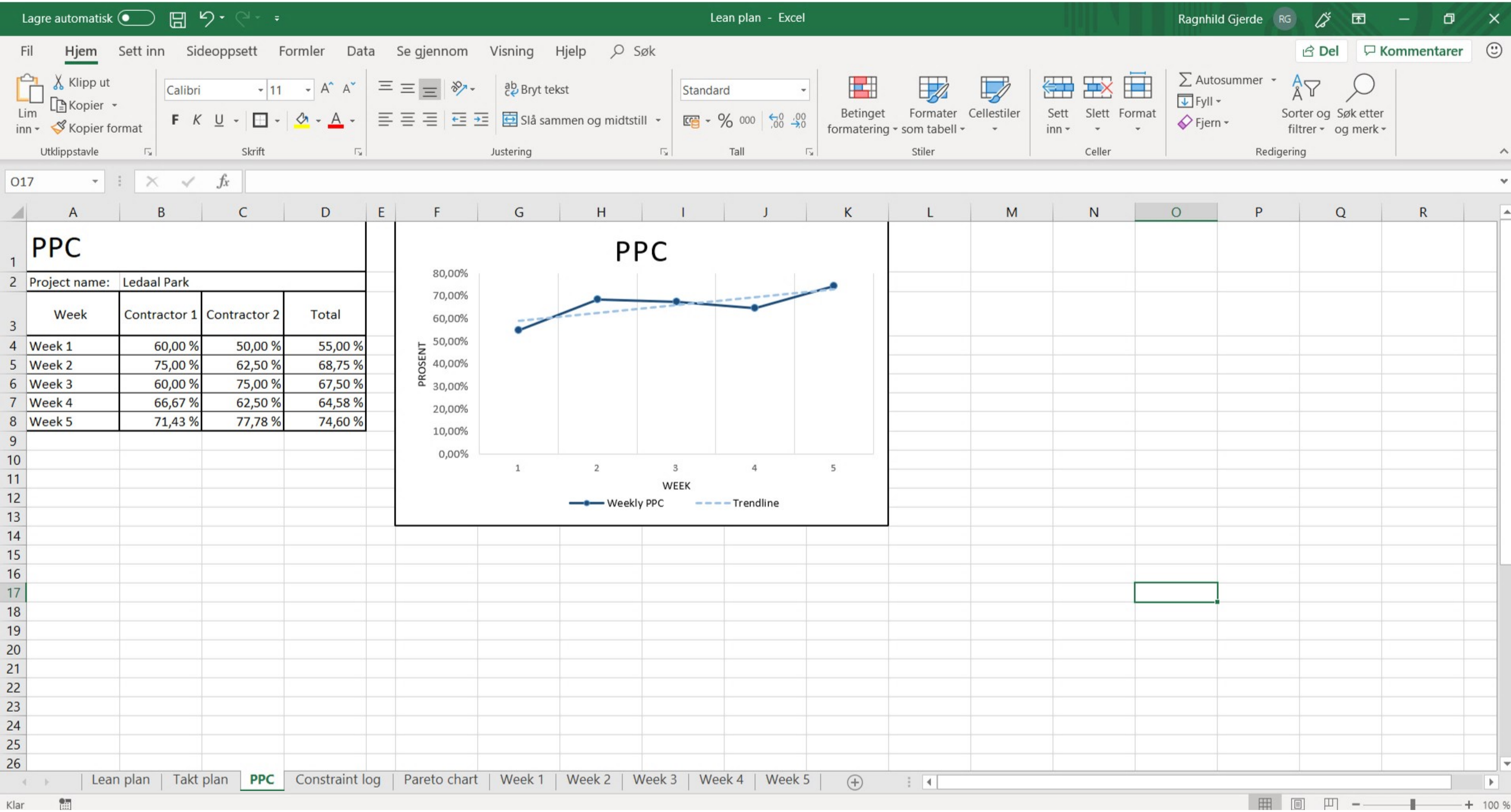


Pareto chart

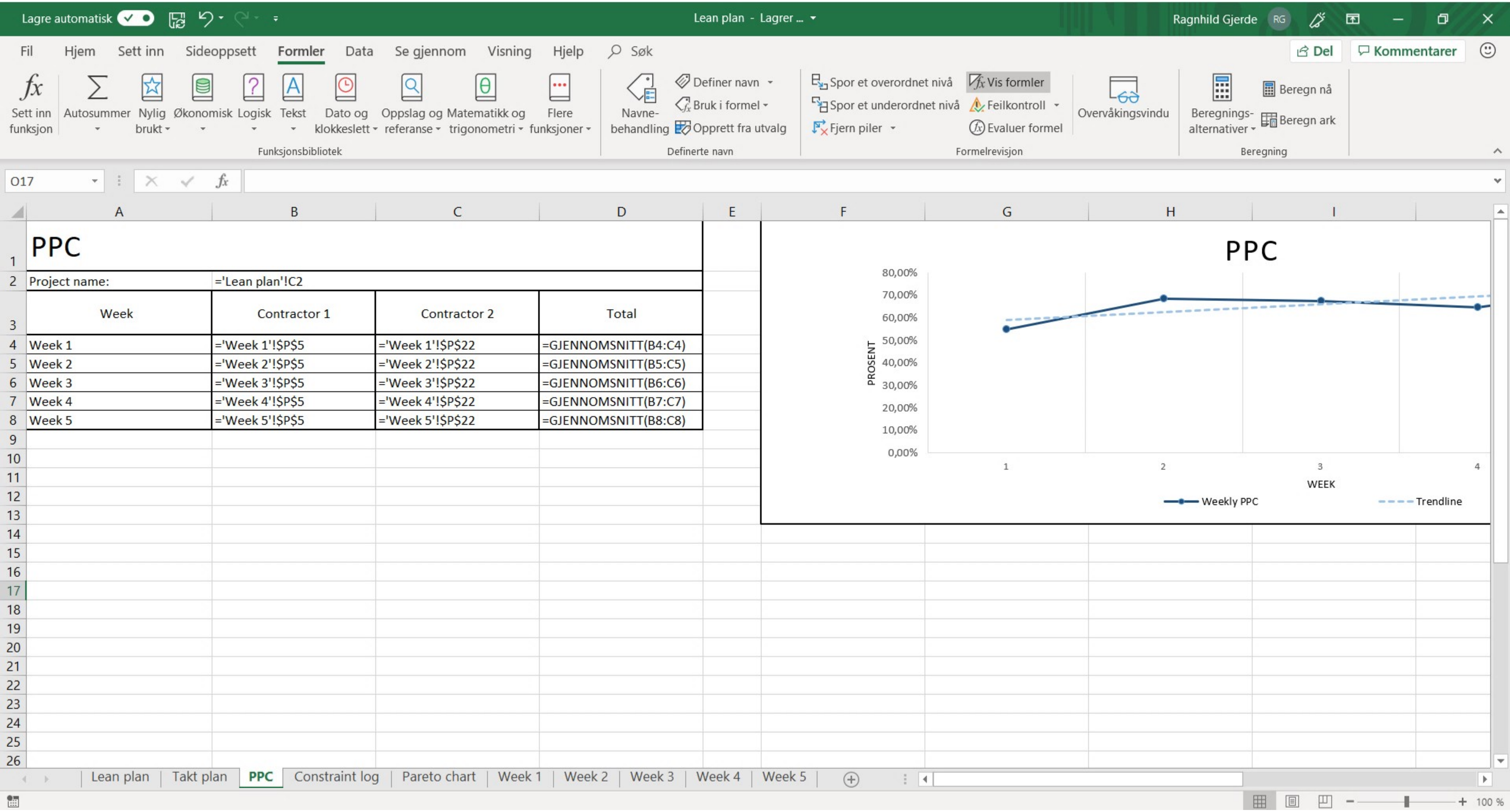
Project name:	Ledaal Park
Phase:	
Area:	
Reasons for constraint	Total no.
Unforeseen conditions	5
Work scope changed	5
Lack of equipment	3
Poor planning	3
Lack of material	2
Earlier task delayed	2
External conditions	2
Lack of crew	1



Lean plan - Lagrer ...
A1
Pareto chart
Project name: =PPC!B2
Phase:
Area:
Reasons for constraint | Total no.
Unforeseen conditions | =ANTALLA('Constraint log'!Q7:Q42)
Work scope changed | =ANTALLA('Constraint log'!J9:J42)
Lack of equipment | =ANTALLA('Constraint log'!N9:N42)
Poor planning | =ANTALLA('Constraint log'!K9:K42)
Lack of material | =ANTALLA('Constraint log'!M9:M42)
Earlier task delayed | =ANTALLA('Constraint log'!L9:L42)
External conditions | =ANTALLA('Constraint log'!P9:P42)
Lack of crew | =ANTALLA('Constraint log'!O9:O42)
Pareto chart
Number of occurence
Constraint
Unforeseen conditions
Work scope changed
Lack of equipment
Poor planning
Lack of material
Earlier task delayed
External conditions
Lack of crew
Lean plan
Takt plan
PPC
Constraint log
Pareto chart
Week 1
Week 2
Week 3
Week 4
Week 5



PPC			
Project name:	Ledaal Park		
Week	Contractor 1	Contractor 2	Total
Week 1	60,00 %	50,00 %	55,00 %
Week 2	75,00 %	62,50 %	68,75 %
Week 3	60,00 %	75,00 %	67,50 %
Week 4	66,67 %	62,50 %	64,58 %
Week 5	71,43 %	77,78 %	74,60 %



PPC			
Project name:	='Lean plan'!C2		
Week	Contractor 1	Contractor 2	Total
Week 1	='Week 1'!$P$5	='Week 1'!$P$22	=GJENNOMSNITT(B4:C4)
Week 2	='Week 2'!$P$5	='Week 2'!$P$22	=GJENNOMSNITT(B5:C5)
Week 3	='Week 3'!$P$5	='Week 3'!$P$22	=GJENNOMSNITT(B6:C6)
Week 4	='Week 4'!$P$5	='Week 4'!$P$22	=GJENNOMSNITT(B7:C7)
Week 5	='Week 5'!$P$5	='Week 5'!$P$22	=GJENNOMSNITT(B8:C8)