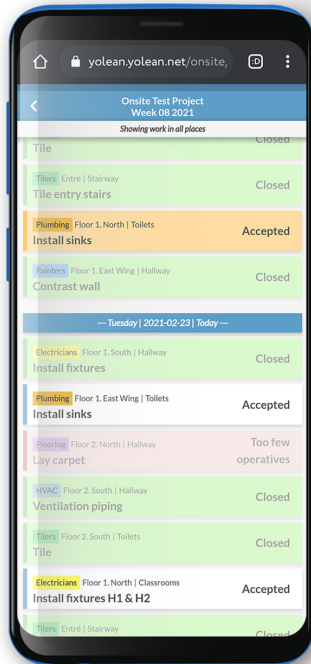




CHALMERS
UNIVERSITY OF TECHNOLOGY



Exploring the Need For and Designing Digital Tools for Production Control

A Study of Current Construction Project Management and the Implications for Design

Master's thesis in Industrial Design Engineering

SOFIA FALKENDAL
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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
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MASTER'S THESIS 2021

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Abstract

Production control, managing the realisation of construction planning into tangible buildings or structures, is an area where digital tools could benefit current processes. The thesis investigates the use of, and requirements for, software in production control, as well as obstacles faced. This in order to provide Yolean, a software for management of product development projects that has recently seen an increase of use in the construction industry, with insights for requirements of their product and how it could be expanded for use on mobile devices.

Interviews, field studies and literature were used to derive insights on the topic. Parallel to this, a research through design approach was utilized and a functional prototype developed to identify the users, use cases, design and functionality needed in a mobile interface for software used in production control. The prototype was evaluated synthetically with scenarios, in context by real users in their daily workflow and used as a mediating tool during interviews.

It was found that management methodologies and tools used at projects examined were outdated compared to recommendations in modern literature, such as lean construction and the Last Planner® System, and that, for the purpose of production control, they underutilized the potential of available technology. As Yolean's product was not originally intended for it, the software lacks support for some of the specifics of production control and its functionality was underutilized as well. Overall, detailed planning was undervalued among interviewees compared to its academically proven effects.

Value was added to Yolean's product in terms of making it portable and readily accessible. Ease of use was found to be vital for adoption. The purpose of a mobile interface should not be to replace production meetings but to ease the process of information flow, gathering communication and documentation in a common platform. Visual material is key in relaying and understanding information, due to the ever changing nature of construction sites. Trust within the project organisation was found to be required for leveraging collaborative functionality, being the primary barrier for benefiting fully from use.

Keywords:

UX, UX-design, Lean Construction, Yolean, Industrial Design Engineering, Production Control, Digitalization, Task Management Software, VDC

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We want to give a huge **thank you** to everyone who has supported us in our thesis work.

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Due to the Covid-19 pandemic, it has been extra hard getting in touch with relevant key individuals in the industry. Even so, we have been able to visit construction sites and gotten to connect via video chats, and we want to direct our special gratitude towards those supervisors, block managers and site managers that gave us their time and valuable input.

Burak "Burre" Atabas deserves the greatest gratitude for helping us in the final stages of this thesis. He is our hero for the time he gave us and the enthusiasm with which he tested our prototype!

Finally we want to thank our examiner Bijan, as he gave us hope and guidance when we felt we were losing track of our thesis and needed someone to talk to.

Sofia Falkendal & Erik Gunnarsson, Gothenburg, March 2021

List of Translated Terminology

The following list presents key terminology for which translations from Swedish to English has been made to avoid discrepancies. Selection is based on the frequency of which terminology has emerged during interviews, observations and relevant readings.

Swedish	English
Arbetare	Worker
Arbetsberedning	Job planning
Arbetsledare	Supervisor
Betongare	Concreter
Blockchef	Block Manager
Byggherre	Developer
Byggmästare	Builder
Entreprenör	Building contractor
Installatör	Installer
KMA (Kvalitet, Miljö, Arbetsmiljö)	QEHS (Quality, Environment, Health and Safety)
Konsult	Consultant
Konsultföretag	Consulting firm
Leverantör	Supplier
Montör	Fitter, Mechanic
Målare	Painter
Platschef	Site Manager
Projektchef	Project Manager
Samverkansunderentreprenör, SUE	Collaborative Subcontractor
Snickare	Carpenter
Tillbud	Incident, near-accident
Totalentreprenad	Turnkey contract
Underentreprenör, UE	Subcontractor
Underleverantör	Subcontractor, Sub-supplier
Yrkesarbetare	Skilled Worker

Selection from Skanska (2017)

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1

Introduction

Construction projects start long before the first shovel hits the ground, with many hours of designing and planning. When the actual construction starts, there are still huge needs for coordinating, re-planning and following up on executed work. This is done through *production control*, which is the coordination of planned and ongoing work out on the construction sites. Production control involves planning and controlling physical work as well as documentation necessary for completion and hand off to the client.

1.1 Rationale

With an increasing number of countries mandating the use of BIM (Building Information Modelling) for procurement of public projects, a revolution of digital tools for construction is imminent. To enable its associated workflows, VDC (Virtual Design and Construction) and ICE (Integrated Concurrent Engineering), collaborative platforms such as Yolean's visual planner are necessary to support lean based methods for project and production management.

This thesis was carried out at Yolean, seeking to further their understanding of this user segment and propose a design for such an application if found to add value to their product offering. Yolean supplies software for management of product development projects and has pivoted to target the specific challenges of design and management in construction projects.

As Yolean's product was originally designed as a general project management tool, specialization towards the construction industry may add extended value to customers. Further, Yolean has received requests by their customers for a smartphone application and is interested in investigating the potential for adding value to this customer segment through this type of product. As the software is used differently in production as compared to construction design, it is of interest to study the impact of the software related to production control as to understand how to best leverage the specific form factor to support the requirements set by these users and their context.

For these purposes, this thesis will investigate the needs related to visual planning in production control of construction projects and how to accommodate aforementioned needs through a research by design approach.

1.2 Aim and Research Questions

The aim of this thesis is to understand how production control is managed on Swedish construction sites using Yolean, as well as sites using traditional workflows. It also explores who the involved actors are, and if roles not currently interacting with planning software directly could benefit through increased interaction and access to information as well as if and how this would add value to projects overall.

Through developing and launching a functional prototype during the thesis work, the aim is to derive a design for a product or service that would add value to Yolean's product offer. By iterating upon the prototype as insights emerge, its ability to generate the value through the proposed functionality will be evaluated. The aim was formulated as two separate research questions:

RQ1: How is planning and/or production control carried out and followed up on in construction projects?

- (a) What tools or software is used?
- (b) What obstacles are faced?

RQ2: How should a mobile interface be designed to add value in the use of Yolean's existing product for production control in construction projects?

- (a) Who is to be the user(s) of the mobile interface?
- (b) Which use cases should the interface support?
- (c) What functionality is needed to support the relevant use cases?

The first research question focused on information gathering and user understanding, and the second on using insights from (RQ1) in developing Yolean's offer as a prototype.

1.3 Process Overview

This thesis was carried out with an approach of collecting data through multiple methods simultaneously as developing a prototype which is part of the result of the thesis work. Figure 1 shows an overview of the process, it will be elaborated on in more detail in Section 3.

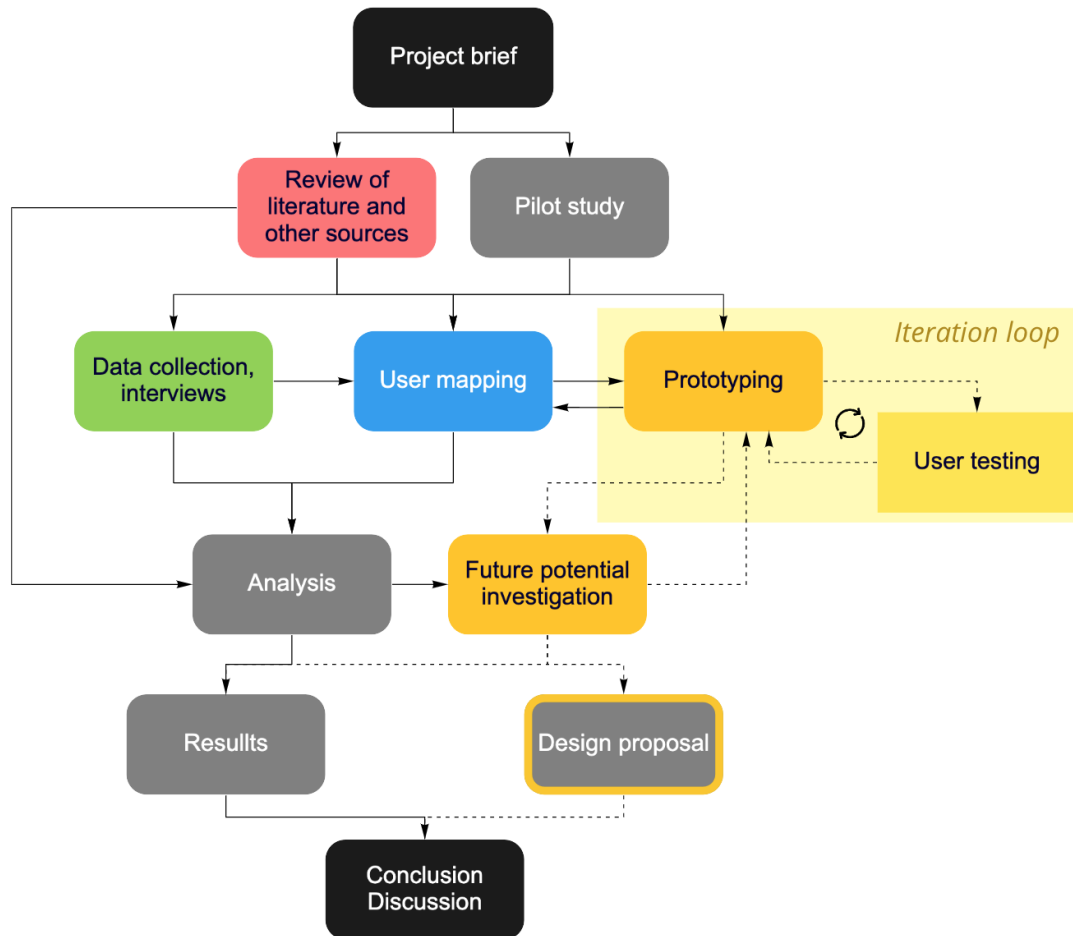


Figure 1: An overview of the thesis process.

1.4 Demarcations

The ambition of this thesis was to visit a wide array of different construction enterprises and their subcontractors, both on site and in controlled environments for interviews, observations, and longer periods of testing the prototype while observing interaction and changes in workflows. However, several factors became obstacles in acquiring access to these individuals and places.

- Due to the COVID-19 pandemic, and regulations, policies and general concerns regarding it, individuals on relevant positions have been (understandably) reluctant about site visits. The construction site visits have therefore been fewer and shorter. In some cases

video interviews have worked as replacements for physical visits. Inability to make observations on the work places along with interviews has limited analysis but has been accounted for.

- The number of construction projects running the Yolean software in production control in Sweden was at the time of the study limited to a single one. Therefore it was decided that it did not matter what software or tool visited projects used. Field studies would instead be aimed at investigating how any planning- or management tool on sites was interacted with and used to elicit prototype requirements for collaboration.
- The context accurate deployment of the mobile interface was first done in Germany in collaboration with a German consultant company. Due to language barriers and cultural differences information may have been lost in translation or distorted, possibly having resulted in limited analysis.
- The functional prototype developed in this thesis is a frontend application. It relies on data and functionality already available from the backend/server for much of its functionality. Hence, the ability to implement new functions, not yet available in Yolean's existing product, was restricted.
- The width of this project spans several research areas, namely Interaction Design, Construction Management as well as Project Management Theory and Software. As of this, the thesis project could not cover all subjects with the same depth as compared to designing for a more generalized purpose or activity already familiar to the authors.
- The end user of the prototype designed during this thesis was not known from the start and the determination of who this user should/will be was in itself part of the research. This study has deliberately refrained from narrowing the scope of this aspect as to remain open to explore the most value adding solution.
- This thesis has had to deal with the challenge of deciding between designing for the optimal workflow for users compared to how study participants are using the tools at their disposal today and how they would prefer the system to function. As testing has been reliant of users trying out the design in their daily work, the prototype has had to comply with their demands on functionality for them to agree to participate.
- The available time for the thesis work was 20 weeks, from October of 2020 to March of 2021.

2

Theory and Background

Following sections explicate necessary theoretical background in order to understand the production of construction projects and conditions affecting them. Relevant management- and organisational structures and methodologies are covered as well. Further on, Yolean's product and its position within the aforementioned context is explained, and relevant alternatives to it are presented. Finally, relevant design theory related to the prototype and design proposal is touched upon.

2.1 The Construction Industry and its Organisation

Different types of construction projects act under different conditions and each provides its set of unique challenges. Most projects can be categorized into one of the following three types:

- **Housing construction** - floor layouts are similar and this type of construction has many repetitive elements.
- **Other building constructions** (e.g. schools and hospitals) - where the execution and final appearance may hold more uncertainty, repetitive workflows are harder to establish and specialty facilities, such as lab environments, may impose complex requirements. Designs are also more likely to change during production.
- **Ground construction** (e.g. roads, bridges and tunnels) - where surroundings, (unexpected) geotechnical aspects or archaeological findings can prove problematic.

Adapted from Josephson (2013).

There is also a difference between new construction, extension of a construction and reconstruction. The two latter are prone to more uncertainty as one may not know what will be found when demolishing old walls or floors. A predictable project (new production), often with elements of repetition, will have better preconditions for making processes more efficient. It is essential to reduce as much uncertainty as possible and identify repeatable elements for any project in order to streamline processes (Josephson, 2013). The reality of large construction projects is complex, and they are often conducted by temporary company structures (Fig. 2). The main contractor(s) will form a temporary organisation on site with subcontractors and their joined forces work the project towards completion. The scale of a construction project, and whether it is a private or a publicly procured one, also affects the organisational structure. Who the main contractor is, is also a factor, as which competences and equipment a company controls internally may vary.

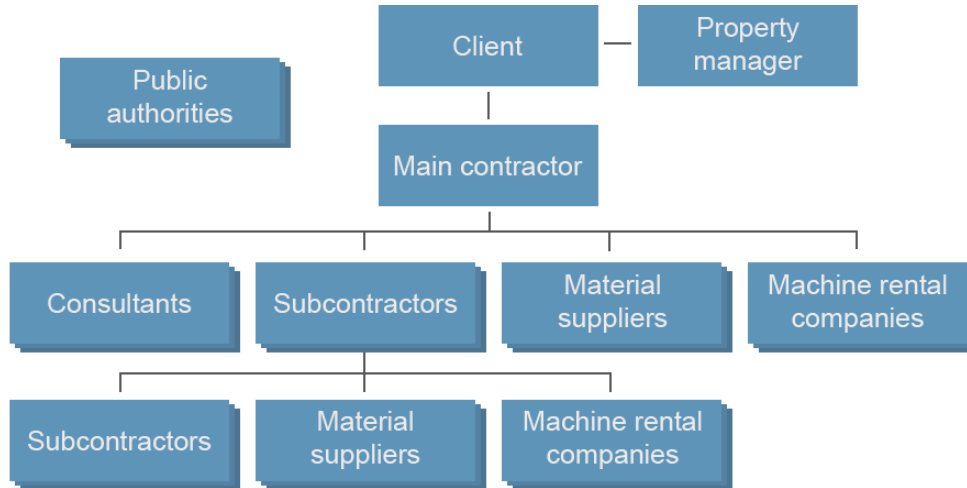


Figure 2: The general organisation of construction projects with a main contractor, adapted from Josephson (2013).

There are constant and changing parts of an organisation at a construction site. The building contractor is a part of the project organisation for the entire production phase. Collaborative subcontractors can also be involved throughout the entirety of a project, but other subcontractors may only take part for a few months, weeks or days.

Ideally, the process of a construction project is linear with each phase being completed before the next one commences (Fig. 3) but in reality, new requirements can emerge during production. At times, the project planning process is still ongoing when production is initiated. Deviating from the ideal process causes disruptions in succeeding activities but also enables increased understanding of groups as more communication is necessary. In real construction processes there are always unforeseen events interrupting the ideal process (Josephson, 2013).

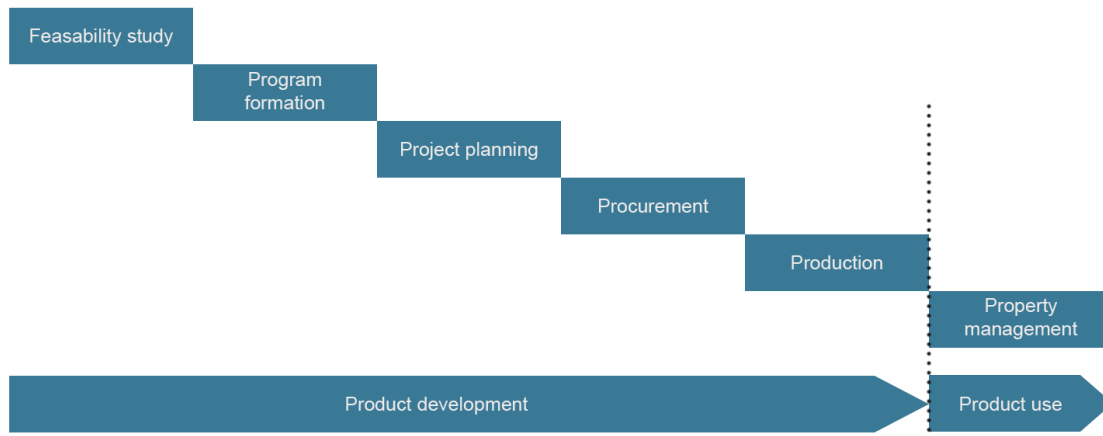


Figure 3: The ideal process of construction projects - Josephson (2013).

Josephson (2013) divides construction activities into three types. *Operational processes* are the flows of activities that directly adds value for a customer during the production phase. Removal of an operational process would result in an incomplete product. *Support processes* are activities that aid operational processes. *Management processes* are activities aimed at deciding the strategies and goals of an organisation. In themselves, support- and management processes generate no tangible value for the customer, but are necessary for the operational processes to function and for the organisation to perform the correct activities. The support- and management processes must be balanced across the operative processes in order to not hinder it by being too slow or risk becoming irrelevant if performed too far ahead.

According to Josephson (2013), it can be beneficial to view the result of the processes as either *value-adding work*, for the product or customer, or *waste*, work that consumes resources without adding value. Supporting activities, that are required for the value-adding activities, can be viewed as *forced waste*, contrary to activities that nor directly or indirectly adds value that are called *pure waste*. Depending on perspective and attitude, whether you are a customer or a contractor, planning of physical work could be perceived as either pure waste or forced waste. Companies which work with long-term goals to reduce costs and increase profits, regardless of industry, profits from experience to decrease process variation, making processes more predictable and comparable between projects. In the construction industry, companies tend to work short-term with cost reductions, possibly explained by that every individual project, with its unique temporary organisation, is expected to generate a surplus. This is why cost reduction attempts have been less effective in the construction industry compared to other industries (Josephson, 2013).

Josephson (2013) also identifies that construction differs from other industries in the sense that projects are to a greater extent funded by the public sector. This means that they are more regulated than for example the automotive industry. However, entry barriers in the construction industry are low, almost anyone can start a small business and get hired as a consultant or subcontractor within a few days. In 2019, there were 107,582 registered businesses in the construction industry in Sweden (Byggföretagen, 2020b). Out of these, 87% had four or fewer employees, which also reflects the company sizes for architect- and consultant firms (Josephson, 2013) inferring that a development of the entire industry is challenging due to the vast number of actors. This further implicates that the industry is fragmented (Josephson, 2013) and that it should be thought of as several industries with variation in type of output product, where the production process is adapted for the customer in each project.

A construction project can be described as

"A number of *groups or individuals*
with special *knowledge and abilities*
performing different *tasks*
in a *coordinated manner*
under the influence of a *context*
to solve a *common complex problem*
during a *limited time*"

Adapted from Josephson (2013).

This kind of organisation trains organisations' and individuals' ability to be flexible problem solvers, but lacks in creating more effective joint processes resulting in variation in end-result and risks.

2.2 Construction Planning and Management Methodologies

As Yolean's product is created to support a lean based workflow, understanding lean methodology and its place in the construction industry is vital to designing for it. The following subsection covers this broad subject briefly, it being a science in itself, as well as other commonly used methods for planning, in regards to what is relevant for this thesis.

2.2.1 Critical Path Method

The *Critical Path Method* (at times referred to as Critical Path Analysis) or CPM originates from the US Navy's development efforts during the late 1950s (Antill & Woodhead, 1990). In CPM, the project plan is represented by a schematic diagram depicting the sequences and interrelations of activities in the project. This affords the analysis needed to determine the most efficient path for execution and how alterations of the plan will affect the outcome of the project. Importantly, this method can be used to identify which delays or variations in the schedule that can be allowed or which will require immediate remedies due to constraining other activities. When performing CPM, one of the goals is to attempt to balance the cost-time problem to account for both direct and indirect costs (e.g. overhead costs) in order to determine the most economical use of available resources (Antill & Woodhead, 1990).

2.2.2 Location-Based Scheduling

Location-based scheduling, LBS, is part of *Location Based Management Systems for Construction* (LBMS), a comprehensive planning, scheduling and control system for construction projects. LBMS is designed to reduce risks, production costs and material waste while improving subcontractor performance, site harmony and deliver more certain, as well as higher, quality outcomes (Kenley & Seppänen, 2010). The argument for developing LBMS was the view that CPM did not recognize the repeatable nature of construction projects and that this can be leveraged with efficient management. According to Kenley and Seppänen (2010), instead of becoming a functional production schedule, CPM bar-chart plans are often found to be produced for the sake of satisfying the customer. The CPM diagrams are then repeatedly updated with how the site management actually has to schedule the work, indicating that the schedules generated by CPM have poor feasibility.

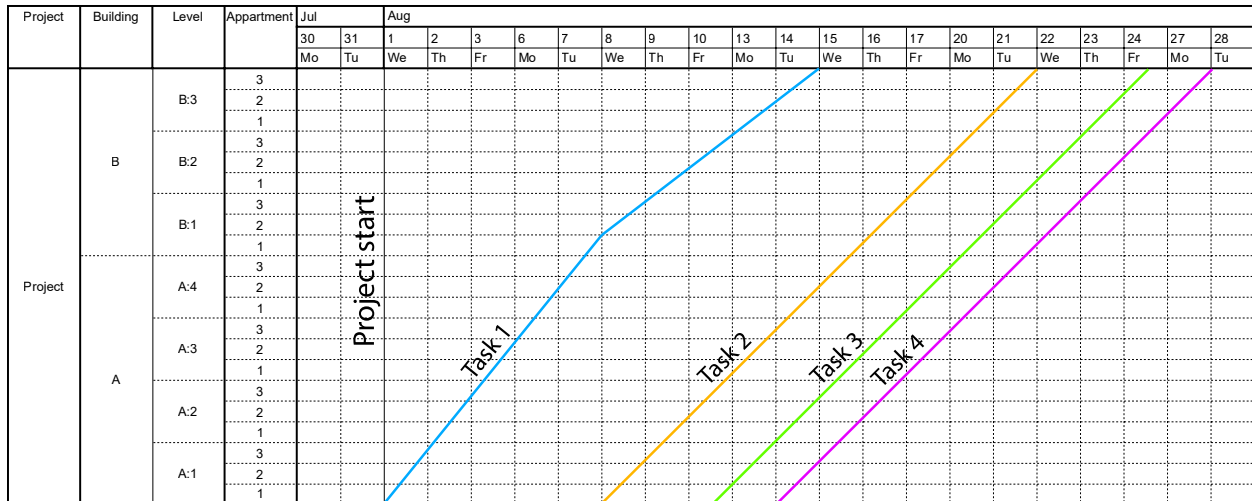


Figure 4: An example of a LBS diagram, adapted from (Andersson & Christensen, 2008)

LBS (as illustrated in Fig.4) is a variation on linear scheduling methods for repeating work such as *Line-of-Balance* and strives to allow resource groups to perform their work without interruption caused by other resource groups, in analogy with lean principles (Andersson & Christensen, 2008). Through scheduling by location, the schedule itself becomes more easily understood than conventional bar graphs and overlaps where teams are blocking each other can be avoided. As the graphs also indicate pace of work in relation to others, resources can be balanced to where they are needed in order to avoid standstills. In LBS, the completion of ones work before moving onto a task at another location is a core fundamental. Compared to conventional planning where subcontractors are often viewing activities as deadlines and are free to schedule their work, LBS accounts for subcontractors' resources in the scheduling which increase its feasibility (Andersson & Christensen, 2008).

2.2.3 Lean Methodology and Lean Construction

The lean production philosophy, popularized as the production industry witnessed the success of the *Toyota Production System* (TPS, developed by Toyota between 1948-1975 (Bhattacharya, 2014)), has seen widespread and successful implementation in manufacturing and other industries. Meanwhile, the AEC (Architecture, Engineering and Construction) industry was comparatively late to other fields with adopting their own version of lean, now called lean construction, as the potential benefits that had been proved achievable in manufacturing were introduced to the AEC field through Koskela (1992). TPS rests on thirteen so called pillars (Kanban Zone, n.d.-d), where *Just-in-Time*, *Genba*, *Kaizen* and *Muda*, *Muri*, *Mura* are some of the more known to western audiences and practitioners of lean philosophy.

Just-in-Time (JIT) strives to increase efficiency by only producing products "when they are needed and in the quantity needed" (Kanban Zone, n.d.-a). Benefits, among others, of JIT are lowering storage costs and reducing or eliminating waste (Kanban Zone, n.d.-a). *Muda* is the Japanese word for "waste" or non-value-adding activities (Womack & Jones, 1996). *Muda* is

interlaced with *Mura* (unevenness or variation) and *Muri* (overburden) to be successfully evaluated, as those are generally the root-causes of *Muda* i.e. waste (Kanban Zone, n.d.-c). *Kaizen*, *kai* meaning "change" and *zen* "for the better", is the philosophy of continual improvement and should be practiced at every company level (Kanban Zone, n.d.-b). Part of *kaizen* is to lessen *muda*, *mura* and *muri*, hence the thirteen pillars of TPS are not standalone methods or philosophies, but work in tandem to address each other.

Womack and Jones (1996) prescribes *lean thinking* as the "antidote" for *muda*. Summarized, modern lean methodology, adapted and inspired from TPS, can be described as attempting to minimize waste in order to maximize value. However, it also encompasses a framework to achieve this purpose through methodologies of identifying and eliminating waste, implementing the philosophy in organizations' work on all levels through good leadership and organizational culture. Lean "is *lean* because it provides a way to do more and more with less and less [...] while [...] providing customers with exactly what they want" (Womack & Jones, 1996). Womack and Jones (1996) also distill the lean principles into the following five:

- Specify the value desired by the customer
- Identify the value stream for each product providing that value and challenge all of the wasted steps (generally nine out of ten) currently necessary to provide it
- Make the product flow continuously through the remaining value-adding steps
- Introduce pull between all steps where continuous flow is possible
- Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls

Although lean has proven to be effective in increasing productivity, according to Rüttimann and Stöckli (2016) the various tools developed as part of TPS are often misunderstood by aspiring practitioners as being independent of one another. Although benefits can be gained from applying a single methodology, the true potential of lean is achieved when associated tools are used in synergy and the practitioners understand the core fundamentals of lean thinking. Furthermore, Mossman (2009) argues against the commercialized version of lean, often promising to make companies more money by reducing waste. Instead, waste elimination should not be in focus but will be a byproduct from successfully implementing lean methodology with the primary goal of creating and delivering value to customers and end users alike.

According to Koskela (1992), for successful implementation, key factors are creating an environment where problems can be openly discussed and tackled by the team and actively learning from these problems is encouraged. This requires both excellent leadership as well as including workers in lean thinking, not just forcing specific tools and principles upon them, nor designating certain employees alone to perform them.

2.2.4 Last Planner® System

The Last Planner® System of Production Control (LPS) is a methodology for collaborative management of the production of construction projects. The "last planner" refers to the person ultimately responsible for the task being executed, i.e. trade workers' foremen or supervisors. LPS aims to involve these users in the planning and scheduling activities and by their engagement leverage the shared knowledge to generate a realistic and achievable plan for executing the project.

LPS contains five components for production control (Carr, 2018) (Ballard & Tommelein, 2016):

- *Master Scheduling* - Planning for the entire project from start to finish, defining relevant milestones, phase duration and overlaps.
- *Phase Scheduling* - Collaborative planning for a phase of the project, i.e. how to achieve a certain milestone. Typically six to twelve weeks ahead. Utilizing *pull planning* (Ballard & Tommelein, 2016), a method to create shared understanding for the purpose of activities as well as identifying prerequisite conditions through co-designing the process to achieve a certain milestone backwards from finished product to start, to specify hand-offs and conditions of satisfaction.
- *Look Ahead Planning* - Collaborative weekly meetings to identify potential issues with the schedule so as to update the plan if needed. Break down tasks from processes into operations and design these.
- *Commitment Planning* - Weekly collaborative meetings where last planners discuss and commit to executing on the scheduled work by making reliable promises.
- *Learning* - Last planners and managers weekly reflect upon how they managed to execute on the previous week's plan and adjust upcoming plans based on the lessons learned. Utilizing data metrics such as *percent plan complete* (PPC), *Task Made Ready* (TMR) and *Tasks Anticipated* (TA) with LPS tools such as *the 5 Whys* (essentially the process of repeatedly asking why) to identify root causes and design countermeasures to prevent recurrences.

The master scheduling is performed by the architects, project owner and client, the rest by relevant managers and last planners.

It should be noted that LPS is a **specification** for project production planning and control, not a specific way to plan and control production in projects (Ballard & Tommelein, 2016). It is instead a set of requirements that any specific way must fulfill to be considered aligned to LPS. Note also that LPS is not a project control method but a production control method, where the former sets cost and scheduling targets, then monitors progress toward them. The latter steer towards the targets, schedules as to execute on what can be done and figures out alternatives for that which can not.

Ballard and Tommelein (2016) defines the purposes of LPS as follows:

1. Specifying what tasks should be done when and by whom, from milestones to phases between milestones, to processes within phases, to operations within processes, to steps within operations.
2. Making scheduled tasks ready to be preformed.
3. Re-planning/planning to complete, to archive project objectives.
4. Selecting tasks for daily and weekly work plans / deciding what work to do next.
5. Making release of work between specialists reliable.
6. Visualizing the current and future state of the project.
7. Measuring planning system performance.
8. Learning from plan failures.

LPS was designed to provide a predictable workflow and allow for rapid learning so to enable continuous improvement in production. Although LPS originates from early lean theory it was developed through research conducted in the 1980s before TPS was popularized nor lean construction had been introduced, LPS was designed specifically for the construction industry by AEC-researchers (Mossman, 2009) and it does not require participants to be familiar with, or adhere to, lean construction, but only that they are committed to collaboration and striving for working efficiently (Carr, 2018). The Last Planner® System trademark was given by its creators to the lean construction institute which is why it is today associated with lean construction methodology (Mossman, 2009). According to one of LPS's co-creators, Ballard and Tommelein (2016) explains lean as a philosophy of providing value and reducing waste with LPS being a method for deciding how to do so and achieving these objectives. According to Ballard, LPS is by design avoiding all of the three types of waste identified by TPS (muri/overloading, mura/unevenness and muda/what is unnecessary).

Testimonials from practitioners shows that benefits from implementing LPS are: *smoother workflows, predictable work plans, cost reduction, reduced time of project delivery, improved productivity and greater collaboration with field personnel and subcontractors* (Fernandez-Solis et al., 2013). Studies in Denmark and Chile has shown the effect of LPS to reduce the amount of accidents within the same company compared to projects not using LPS with 65% and 75% respectively (Mossman, 2009).

The LPS methodology automatically highlights bad performers as well as bad performing managers. Also, project managers are still in need of policing the use of LPS as with traditional construction management and sanction against bad actors, i.e. contractors not performing their jobs (Mossman, 2009). A survey of LPS implementation showed that the most common barriers experienced by practitioners was resistance to change within the organization, a "this is how I've always done it"-attitude, as well as a lack of commitment to, or negative attitude towards, LPS implementation. Additional barriers, listed in order of frequency, were lack of skills, training and experience (Human capital), lack of leadership or organizational support as well as lack of stakeholder support (Fernandez-Solis et al., 2013). Challenges with contract or legal issues, lack of collaboration, bad work ethics or cultural issues were rare occurrences.

2.2.5 VDC - Virtual Digital and Construction

Virtual Design Construction (VDC), developed at Stanford University in 2001, is a digital approach to construction projects, leveraging new technologies for increased collaboration. The digital models used are referred to as BIM, and ICE and PPM are methods of working on and with the virtual models collaboratively.

2.2.5.1 BIM - Building Information Modeling

According to National Institute of Building Sciences (2007), BIM is one of the most promising developments in the AEC-industry (Architecture, Engineering and Construction). It is utilized as one of three principles of VDC, being a tool for communication to faster and more accurately plan construction projects. BIM is sometimes referred to as the method but is really just a tool whose usage is part of the VDC methodology.

There are multiple BIM model levels (McPartland, 2017), often referred to as 3D, 4D, 4D+, 5D, 6D, and so on, each higher level adding a new aspect:

3D BIM - The virtual 3D-model used can be divided into its building blocks in a CDE (Common Data Environment). It is similar to a CAD-model with information such as materials, mechanical strength, finish and so on is connected to all components but differs as components are and defined as common construction elements. A wall in the model is defined as a wall, a door as a door and so on. The level of detail increases gradually during the planning phase.

4D BIM - Construction sequencing is applied to the model. Thus it can be visualized how the construction will look before production begins and how structure is incrementally added until the construction is finished. The 4D-level model also holds information regarding suppliers, installers, task descriptions, and estimated time frames for the sequences. The data can be used for planning real work and deliveries efficiently as well as minimizing clashes in the workflow.

5D BIM - Cost analysis is added as part of the model. Both for material, installation, and supporting elements such as scaffolding or cranes needed that are not part of the construction model. New cost calculations can be forecasted in real time when changes are made to the drawings making the effect on budget by a proposed change immediately evident. This BIM-level should also contain lifespan and service costs of the building components.

6D BIM - Project life-cycle information, or iBIM (integrated BIM) supplies further information on maintenance type, instructions, and when it is expected to be needed. This information can be used for decisions on whether cheaper or more durable materials should be chosen for long term cost efficiency, already in the project control phase. The information can also be valuable to the property manager post project completion, and updates in the model should be made as time progresses and renovations and maintenance are carried out.

UK Construction Online (2018) further defines four BIM levels of maturity:

Level 0 BIM - CAD is used but only in 2D, paper based drawings are the output and the level of collaboration is very low.

Level 1 - 3D CAD-models are used for conceptual work, drawings are still in 2D but data is shared through a CDE. Stakeholders have no access to the models.

Level 2 - Even though not every stakeholder works on the same model, 3D-models are used by everyone and there is a greater amount of collaboration. Data is shared in the same file format and this enables a centralized BIM model to be generated to identify potential clashes. This level makes use of 4D and 5D BIM.

Level 3 - At this level, different disciplines are in full collaboration. The common model is hosted where any member has access to it. Everyone can add to or modify the model and conflicting data can be removed.

According to Yang and Chou (2018), governmental projects are the main beneficiaries of BIM implementation, and it is thereby reasonable that they are the primary initiators of increased BIM implementation world wide. In the United Kingdom, as per the Government Construction Strategy (Infrastructure and Projects Authority, 2016), level 2 BIM is mandated for centrally-procured public projects as of April 2016. Examples of other countries with some level of BIM mandate are China, Singapore, the US, Japan, South Korea and the Netherlands (Cheng & Lu, 2015). In Sweden, the introduction of a governmental BIM mandate was motioned to the Swedish Parliament in October 2020 (Dibrani, 2020) and has received the Parliaments support and is being further inquired as of the time of writing this thesis.

2.2.5.2 ICE (Integrated Concurrent Engineering) & PPM (Project Production Management)

Integrated Concurrent Engineering (ICE) is a culture and set of methods originally developed by TeamX at NASAs Jet Propulsion Laboratory in the middle of the 1990s (Kunz & Fischer, 2012). ICE is a multi-discipline and multi-stakeholder workflow for collaboration designed to rapidly generate designs with consistently high stakeholder approval ratings. In VDC, ICE is used to gather all relevant stakeholders during ICE-sessions where efficient use of technology is leveraged to ease communication and understanding through visuals such as 3D-models. Sessions should be short and distraction free, with a culture of collaboration and low management supervision (Kunz & Fischer, 2012).

As an illustration for what this encompasses in practice, one Swedish construction firm, Arcona, lists the following participants on their planning meetings using ICE (Arcona, n.d.):

- Site manager
- Chief planner
- Architect
- Construction engineer
- HVAC planner
- Piping planner

- Electrical planner
- Landscape architect
- VDC engineer
- Client/Developer

Project Production Management, PPM, consists of viewing construction as an operation, a continuously repeatable process, of a production system generating goods through the processing of material (Project Production Institute, n.d.). This perspective allows for the leveraging of methods from Operations Science in order to control the systems behaviour.

2.3 Tools used for Construction Project Task Management

This section briefly presents software and tools for project planning and project management which were used or mentioned by participants in this study and that are relevant for comparison and analysis. Additional software solutions exist with similar or rivaling functionality, especially when viewing the market in a global perspective.

2.3.1 Analog tools

Walls or whiteboards with sticky notes for tasks and reminders are common for visualising work or tasks. Usually the board space is divided into columns and rows which can represent days/weeks, who is responsible for the task, or the location where the task will be performed. One of the two latter is sometimes visualized through color coding notes to match whichever is not represented by the rows, see figure 5. The whiteboards shown here are only a portion of the whiteboards used for planning in this site office.

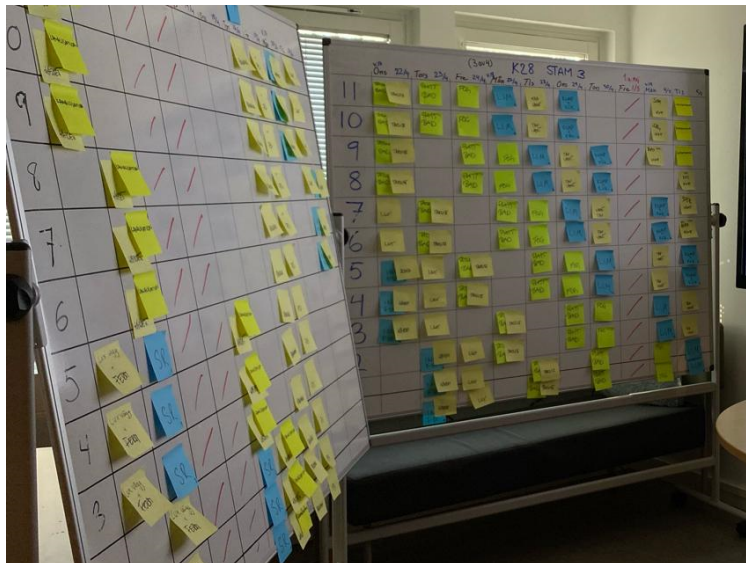


Figure 5: Whiteboards with sticky notes in the office of a construction site.

Visualizing work in this way and having physical objects as a focus point in meetings is done

to ease collaboration between different trades in the production meetings. Worker teams can clearly see planned tasks and, if location based scheduling is used, where clashes may occur with others. Downsides includes the information being fixed in space, and thus unavailable outside of the construction site office. The analog format also requires a lot of manual labour, both in creating and updating the plan.

2.3.2 Lightweight Task Management Solutions

Many sites use freestanding tools to share plans and information. Organisations with Microsoft Teams sometimes use Planner or TO-DO to store tasks online, accessible from any computer, tablet or smartphone. Trello, a free collaborative digital task management board is also used on some sites for the same purpose.

These software are not designed for displaying the huge amounts of tasks or information in construction projects. There are however possibilities to group tasks and assign them to specific individuals.

2.3.3 Traditional (Construction) Planning Software

Primavera, powered by Oracle (Oracle, n.d.), and Powerproject, from Elecosoft (Elecosoft, n.d.) are tools which allows for planning and cost calculation from initiation to closing of a project. They produce charts (see Fig. 6) which looks similar to Gantt-charts. The software can, based on the hourly rate put in for tasks or trades, recalculate costs for a project if an activity runs overtime and is updated in the software. Powerproject is used by over 35 000 users in Europe and they claim the construction industry as one of it's areas of application.

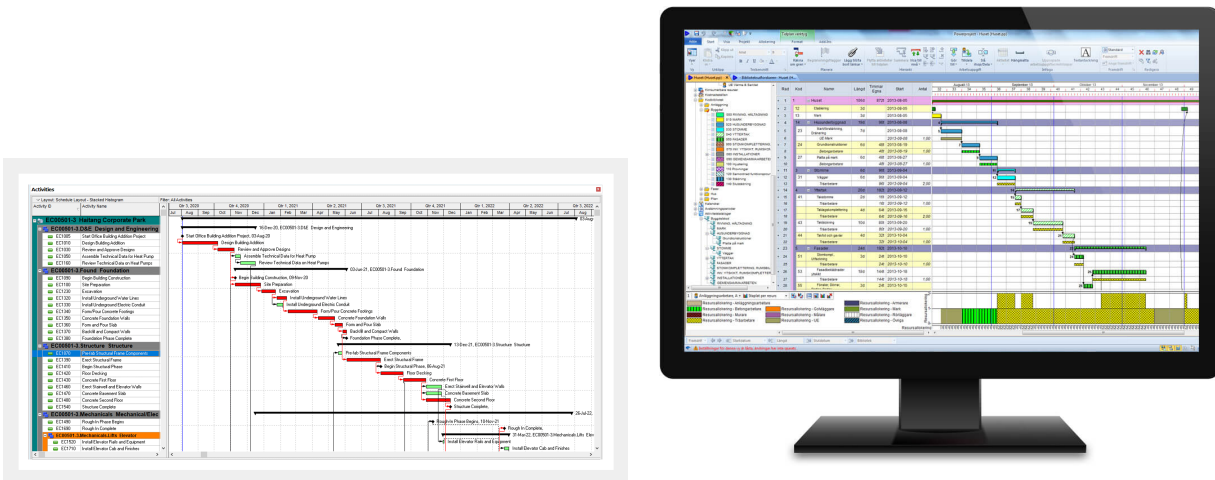


Figure 6: Left: Working view in Primavera (Oracle, n.d.).
Right: Working view in Powerproject (Elecosoft, n.d.).

2.3.4 VDC-solutions for Production

Some sites use software systems for collaboration and leveraging BIM models during the production phase of projects of which *Dalux* was primarily encountered during this study. These tools seemingly consist of a suit of software tools including mobile and desktop applications as well as cloud hosting of files in the shared platform. Functionality includes access to blueprints, BIM models, photo documentation, checklists, progress tracking and communication of issues (Dalux, n.d.).

2.4 Yolean's Product and their Position in the Construction Industry

Yolean's visual planner was originally intended for management of product development projects. The board view offers varying configuration options to support different projects and project stages. Lately, Yolean has gained an increased customer base in the construction industry, most prominently in construction planning, but also for production control, in Sweden and Germany. This is a customer base which they intend to keep and grow.

The board, largely dependent on user created content, generally looks like a calendar view with notes, inspired by methods involving physical post-its, with an alterable time span between one day to a year horizontally. Note that it is not possible to scroll in the board, so if a project contains very many notes, the system will give the user warnings so that no notes in the board can be missed.

Every project needs *Wheres* (not necessarily physical locations), *Workflows* (sub-locations), and *Trades*, the latter also have custom colors assigned to them. *Wheres* are ordered in the board in the same order as in the project settings where they are configured, as are *workflows* and *trades* in sub-ordinal views. Users can choose to display all *wheres*, *workflows* and *trades* vertically, or filter for at the time relevant ones in the filter menu. If the project group has a set meeting day every week, this can also be highlighted in the time line bar.

Yolean is a cloud based software as a service (SaaS) accessed through the web browser. The board is suitable for display on a large touch screen and is usually the focal point for participants in meetings. The board, or selected content, can also be exported in various formats for print or offline display.

There are different note types in the board, with some shared and some unique functionality:

- *Job notes* are digital post-its with tasks, and are assigned to a *trade*, *workflow* and *where* when added to the board, analogous to Location based planning 2.2.2. The work cards have the same colors in the board as their assigned trade, uncommitted tasks are faded in the board until they are *accepted*. This generally happens in meetings as a way of committing to tasks in front of a group. Work cards can span one to ten days, where each day in the board displays a copy of the work card. When a task is completed, the corresponding work card is manually *Closed* in the board, and a check-mark is appended to it. If the task is attempted but unsuccessful, or not performed, it can instead be closed with a

deviation, by selecting a standard or customized *root cause* denoted by a "X"-symbol to it.

- *Weekly Task notes* have the same behavior and functionality as job notes, but occupy a whole week.
- *Deliverables* are used to signify the deadline of a part of a project.
- *Milestones* appear as a vertical line in the board and signifies the the deadline of a part of a project.
- *Blockers* are notes that signifies that work cannot be done in a specified location at the day and time they inhibit in the board.
- *Questions* are added to the board similarly to job notes, but also requires selecting who the question is from. Both questions and work cards can be assigned to board members, people who have log-in credentials, and questions can also be followed by other members. If an answer to a question is considered to be a decision in a matter, the response is marked as such and logged in a *decision log* to support its traceability in the project.

Notes can also be customized in the board settings so to represent what makes sense for each specific project. *Labels* can be applied to notes and appends a customized icon to them. By configuring labels in the project settings and adding labels to selected notes, the filtering possibilities in the board are increased. By also utilizing the functionality of connecting notes by their dependent relations, projects can be further visualized and comprehended as a flow of activities.

2.5 Usability and Design Theory

Products, whether they are physical products or digital interfaces, are "becoming ever more complex in terms of the features and functionality they contain" (Jordan, 2002). When developing products, it needs to be ensured that designers take into account users' limitations and needs for products to be useful, at the same time as people become more resistant to tolerating products that are hard to use. Usability - the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2018), is important, and this chapter covers basic principles of design relevant for this thesis.

2.5.1 Seven Fundamental Principles of Design

If it is possible to identify which actions that are possible, and what state a device is currently in, a product can be said to have good *discoverability*. It should also be easy to determine, after an action has been made, the new states and what have been changed through continuous *feedback*. For a user to feel in control of a product, they need to have a *conceptual model* of how it works or what can be done with it. With a strong conceptual model, enabled by that the

product clearly indicates through information what it can do, both discoverability and feedback evaluation can be enhanced.

Affordances are relationships between objects and users which allow certain properties. A chair, for example, affords (=is for) sitting, just as a touch screen affords user input. *Signifiers* assures that a user knows where on the screen to touch to expect a result, and is linked to discoverability and feedback. *Mapping* is the way controls are laid out, and good mapping should consider spatial and temporal aspects. The "up" - and "down" arrows on buttons by elevators for example should be placed with the up-arrow above the down arrow as it spatially represents what one expects, and controls used often should generally be more visible (or discoverable) than special features.

Constraints can be physical, such as a fence, but they may also be cultural, semantic or logical. A red light at an intersection is semantic, it does not physically stop you from going past it, but you will not. Passwords keep some people out, 'lock-in' constraints forces an operation to stay active, such as when closing a program on a computer, but it will not be terminated until you have actively chosen to save or discard your work.

The seven principles of design have been formed by the seven stages of action (Norman, 2013):

1. What do I want to accomplish? (What is my goal?)
2. What are the alternative action sequences? (Are there alternatives?)
3. What action can I do now?
4. How do I do it?
5. What happened (when I did that)?
6. What does it mean?
7. Have I accomplished my goal?

which are all questions that the user should be able to answer while interacting with an object or an interface of adequate design. It is up to the designers that these questions can be answered.

The user of an object faces two *gulfs* which must be bridged so that the user can cross them. The *Gulf of Execution* is faced when the user is about to do something with a product (stages 2-4) and the aiding information needed in the interface or product to support the action is referred to as *feedforward*. The Gulf of Execution is crossed when users discover what action to take to achieve their goal. Crossing the next gulf, the Gulf of Evaluation (stages 5-7), happens through the users understanding if they have performed the correct action or not, and whether the feedback is enough to tell them what happened in the product or system. That is, if they can tell the new state of the product and if it is in line with the original goal.

2.5.2 Ten Principles of Usable Design

Jordan recognizes five components of usability related to users' learning curves (Jordan, 1993), all in relation to the ISO-definition of usability (see section 2.5). *Guessability* draws upon how a new user can perform tasks for the first time in an interface. *Learnability* is how well they

perform the same tasks having already encountered the interface, and *Experienced User Performance* (EUP), is how well specified tasks can be performed by experienced users with a certain interface.

Later prescribed by Jordan (2002), *Consistency* is the first of ten principles of usable design, and means that "similar tasks should be performed in similar ways" (Jordan, 2002). After performing a task with a product, the user will generalise the experience and be able to perform similar tasks within the system.

Compatibility, just like consistency, profits on users' past experiences, but in this case from how things work in other places than the interface, i.e. in the "outside world" (Jordan, 2002). The color red for example is associated with danger or shutting something off in most cultures, no matter the context.

Being aware of and making use of *consideration of user resources* implies not to overload a user's capabilities. Usability problems can arise if a product or system requires the use of both hands in a context where the users' hands are already occupied, or forcing a user to speak and read at the same time as these both involve language processing.

Clear *feedback* (also being one of Norman's design principles, see section 2.5.1) is crucial for the user in order to know that an action has at all been registered by the product.

Error prevention and recovery from errors may seem arbitrary, but it is also inevitable that users would never make mistakes. In a usable design, the user will be made aware of that an error is about to be made, or in the least, offer a way for the user to find and reverse the error.

Products should allow for as much *User control* as possible. Default settings are often good at the first use of a product, but it should be clear what the default settings are and how they can be changed.

Visual clarity considers layout of information, which should be possible to take in smoothly in a non-confusing way. Sometimes that could be displaying the chosen option in a different color from other alternatives, and displaying an appropriate amount of information at a time. Effort of finding what one is looking for should be small, information should not be displayed in cluttered layouts.

Prioritisation of functionality and information calls for e.g. elevated placement of functions that are used more frequently or considered more important or larger lettering for important headlines.

Technology originally used in one context can advance the use of other products in a different setting by applying the principle of *Appropriate transfer of technology*. E.g. remote controls, originally developed for easier use of TV's for disabled people, have enhanced other products as well as now being the standard tool for TV interaction.

Cues as to how to work a system (referred to as affordances and signifiers by Norman, see section 2.5.1) is the tenth design principle *Explicitness*. What functionality a product has and how to operate it should be denoted through its design.

2.5.3 Interaction Cost

Interaction costs of digital interfaces, i.e. effort required by the user to operate it, are exemplified by Nielsen Norman Group (Budiu, 2013) as *scrolling, reading, looking for relevant information, page load time* and *memory load*. These costs are relative and depend on users and devices. Loading time of a website may not be a great burden in terms of cost when connected to high-speed internet, but may cause interaction or attention issues when on an old phone in the middle of nowhere. Looking for relevant information is ambiguous as it is valued differently if information can be found elsewhere. In such a case the user may switch apps or websites if interaction cost is high, and information is not quickly found, but will probably stay otherwise, or refrain from using the app or website at all.

Interaction costs of scrolling are low if the user knows that the information they are searching for will soon appear in the list, and if amounts of reading does not discourage them and makes them leave. Texts should be short and to the point. Further, memory load can be costly if the user constantly need to backtrack in the interface to remember choices they have made. Thus, when an interface involves making choices it should readily visualize those to reduce interaction costs so that the user can focus on what they are accomplishing.

Since interaction cost is relative and there is often more than one way to navigate to the view or information a user is looking for, the expected utility of an interface equals the expected benefits, minus interaction costs (Budiu, 2013). If the benefits of finding the information outweighs the costs, the interface can be said to be useful.

3

Methodology

This chapter covers the methodology used in performing this thesis. Methods are not presented chronologically as some of them were used simultaneously and/or performed over long periods of time or at multiple occasions (see Fig. 7). Briefly summarized, the thesis has been performed with two parallel tracks. The first track being a series of more traditional research methods such as case studies performed through interviews, at times contextual to answer (RQ1). For the second track, a high fidelity functional prototype was developed and tested in order to answer (RQ2) using a research through design (RtD) approach (Zimmerman & Forlizzi, 2014). This allowed for user testing in a live environment with the goal of evaluating proposed functionality in actual use, as well as receiving feedback on the experience of the new workflow. Insights from track 1 carried over into the RtD-process and analysis of both tracks was performed jointly to answer both research questions.

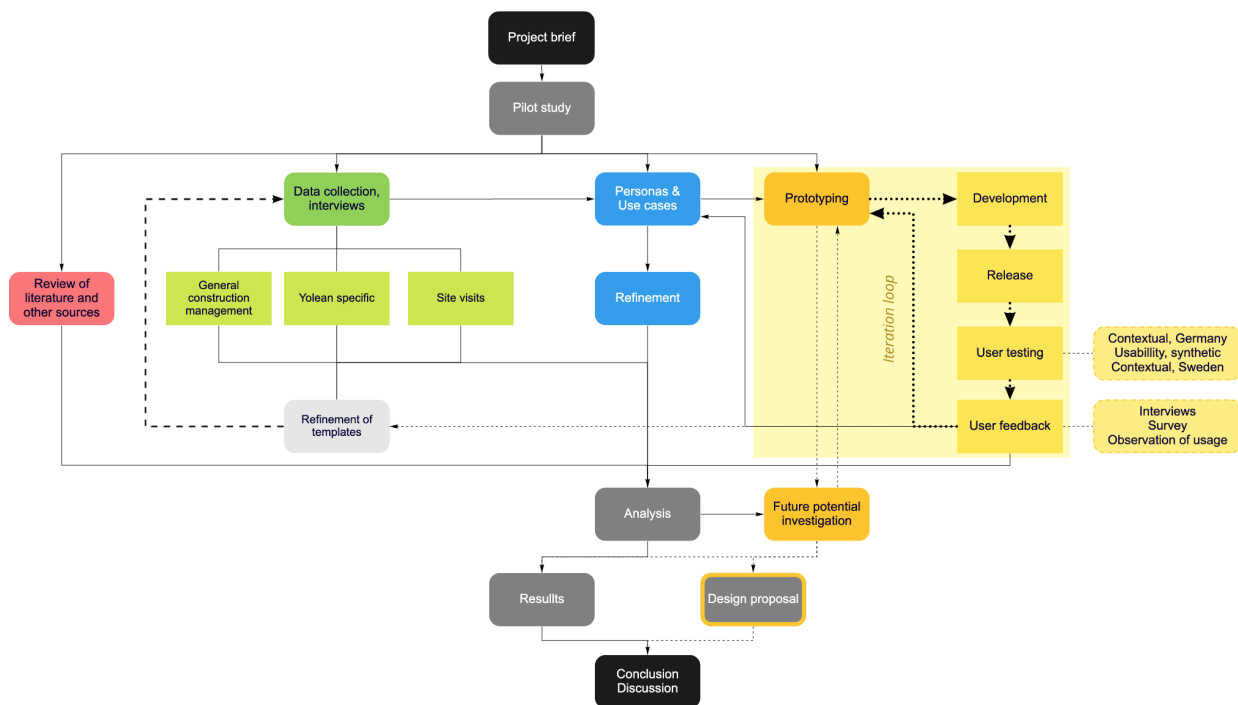


Figure 7: A map over the overall process and use of methodology in the thesis work. The left side represents the first track whilst the right maps out the track of the RtD-approach.

As this project has been dealing with qualitative data, language processing methods were used for analysis in order to understand, sort and cluster data and insights. Some methods covers data collection and processing, while others were used to ideate and develop the prototype based on the findings.

3.1 Interviews

For deeper understanding of the different roles on construction sites, their responsibilities and prerequisites for their work, interviews were performed with participants with relevant experience. These painted a picture of what methodologies, tools, software and platforms for communication were used and for what purposes.

The interviews were semi-structured, and followed a template with opportunity to ask probing follow-up questions on things that stood out as interesting or relevant for the thesis. This made for interviews being colored by what the interviewees considered important or interesting to talk about, as they were not stopped when elaborating on a topic.

In all, ten formal interviews were held with five individuals in the roles of supervisors, block managers or site managers in Sweden. Five out of these interviews involved either testing a version of the prototype (see Section 5.1) or demoing it so to be used as a mediating tool. Out of the five interviewees, two had experience using Yolean’s software for production control.

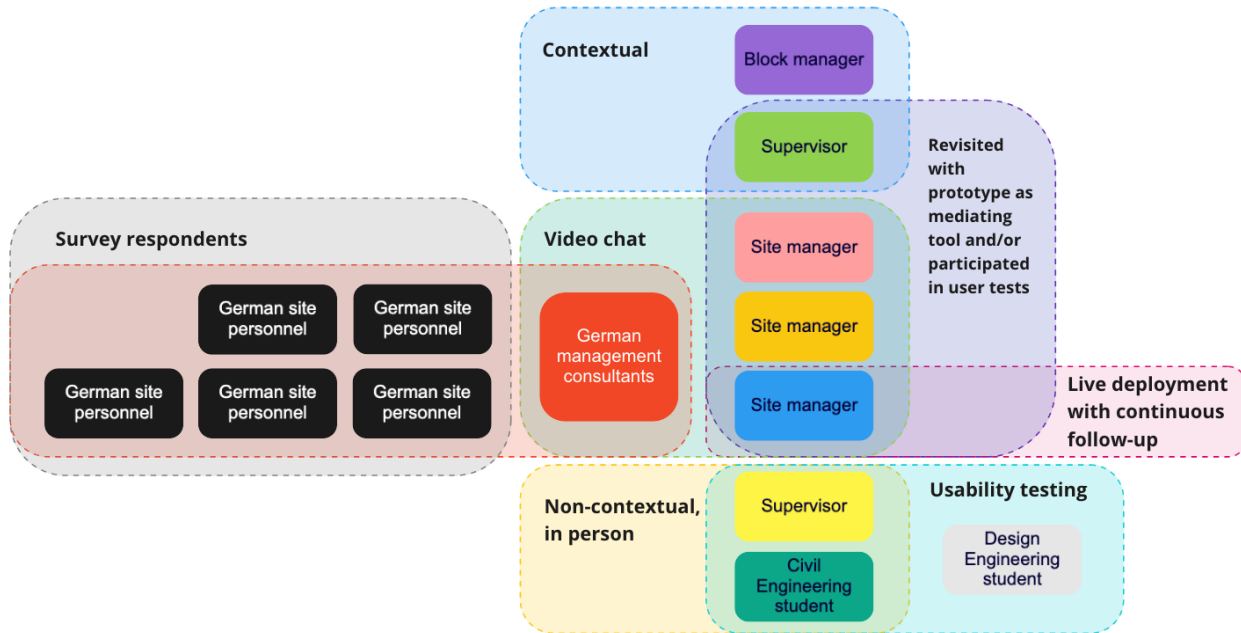


Figure 8: A map over the data collection and how individuals have participated and integrated in the research process.

Most participants in the study were interviewed twice (Fig. 8). The first round of interviews focused on understanding the practical aspects of managing the production of construction projects and gaining insights into work culture and current workflows (RQ1). It also aimed at gathering early input on functionality and design of a mobile interface for Yolean’s current product (RQ2).

The second round of interviews followed up on questions deemed interesting to further explore

as well as discussing and comparing how the interviewees' workflows differed and why. Additionally, iterations of the developed prototype available at the time was used as a mediating tool during the second round. This was to also elicit functionality- and design requirements and identifying barriers for implementing the mobile interface into their current workflow.

Three of the interviews were contextual and conducted during visits at two different construction sites, where field studies (see section 3.2) were conducted in conjunction to them. The rest were made over video chat as the burden of handling the effects of the Covid-19 pandemic left interviewees with limited time for participation as well as causing restrictions regarding visits on sites.

Interviews were also held with consultants at a German lean construction consultancy firm. These were non-structured interviews used to collaborate on implementation for live deployment and receiving user feedback from clients of theirs that they had testing the prototype. Having many customers themselves actively using Yolean's visual planner, they were analogous with stakeholders of the resulting product but also had an agenda of their own in terms of features, functionality and user access which was later accounted for in analysis.

3.2 Field Studies and Observations at Construction Sites

In order to understand the users' context, field studies were useful to get a deeper sense of the environment and the conditions where site personnel work. Overt naturalistic observations (McLeod, 2015) were carried out simultaneously to contextual interviews. Field studies were also necessary to witness if site personnel worked in ways confirmed or refuted by literature. During observations in field it is also possible to elicit behaviours and actions which might be distorted, or not disclosed, in interviews. The interviewee may state in an interview that they usually operate in one way, but observing them in the action can show additional nuances in that behaviour or reveal a difference from how it was described. Follow-up questions were used during the observations when encountering situations where clarification was necessary in order to understand underlying motives or structures.

During production meetings, silent observation was performed by listening in and monitoring how the interaction took place between different roles on the site. The areas of interest for the observations were the information flow, method of communication, and how problems were solved in groups.

In total, three construction site visits were performed with the first being a pilot study early in the thesis project. The two other were visits to another site three months apart where the first visit included observations during a construction meeting and joining a supervisor on their round. The later visit was aimed at testing the prototype in context and for complementary observations and questions which were done while surveying the site with the interviewee.

3.3 Survey

A survey was used as a way to get first-hand information from study participants testing the prototype in Germany. No contact information to participants were collected from the respondents so to not discourage them from filling out the survey. This removed the possibility of posing follow-up questions directly to the respondents based on their individual answers. With this in mind, questions were formulated so as to concrete feedback on defined aspects of the prototype and the user experience.

3.4 Prototyping

The prototype development used data from the early interviews to determine what use cases to support and combined this with design theory and result of design activities such as brainstorming. Feedback was received regularly from testers and evaluation activities and was used to iterate upon the prototype.

3.4.1 High Fidelity Wireframing

Prototyping with wireframes was done in order to rapidly visualize design ideas and functionality without the need for coding. Creating and iterating on the visualization of functionality and information display beforehand saved time and enabled side-by-side comparison between different versions. For example, color coding options (Fig. 9) could be compared for clarity in this early iteration. Apart from sketching layouts on paper, Adobe XD was used.

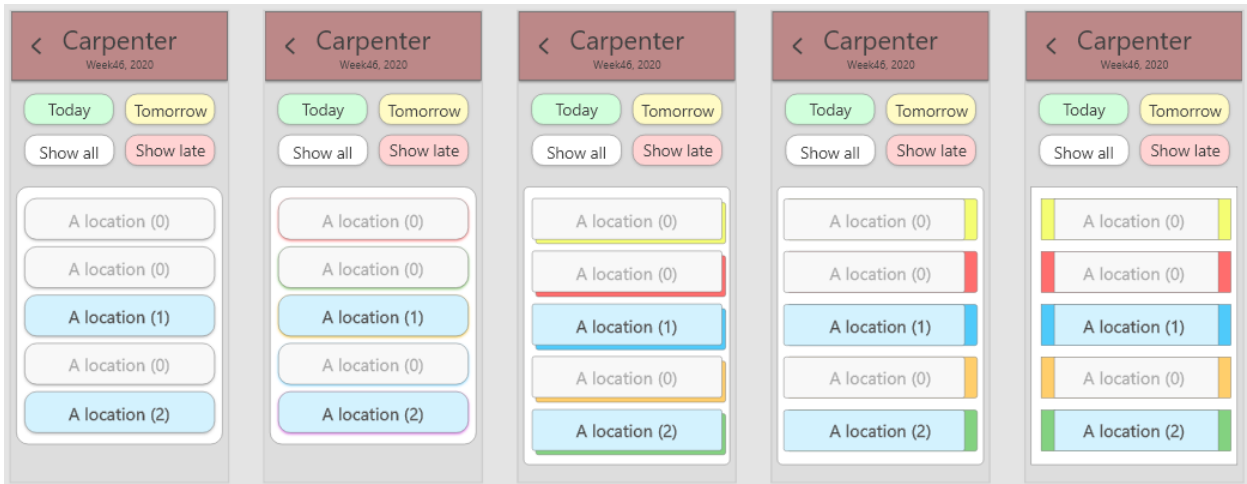


Figure 9: An early snapshot from Adobe XD showcasing how color coding options were tested by wireframing.

3.4.2 Functional Prototype for Live Deployment

The prototype was developed as a frontend web application using the *React JS* JavaScript library which could then be accessed via the web browser of a mobile device, e.g. Google Chrome. No backend alterations could be performed except by Yolean's developers on request, hence, the

interface relied solely on functionality and data already in place in Yolean's board view. This worked out well for the basic features of the application, however, for testing certain features, workarounds were made to recreate or imitate functionality by utilizing existing functions differently than intended (see Section 5.3).

For participating construction projects, re-routing in Yolean's dashboard was enabled so that the mobile interface was automatically displayed whenever users accessed Yolean via a mobile device. This made the login process the same as to how users would sign in through a desktop browser so to avoid issues or confusion regarding access to the interface.

3.5 User Tests

User testing was a part of the RtD-approach. Both synthetic and live tests were done with the functional prototype and insights were continuously used for iterating on the prototype. The tests aimed at providing insights to (RQ2).

3.5.1 Synthetic Usability Testing

The purpose of the usability testing was to confirm that the prototype was intuitive and that usability issues would not be a source of errors when validating the functionality of the prototype in live testing. The usability tests were used to test clarity, guessability and functionality of the prototype. Through a scenario based on stipulated use cases, users took on the role of a supervisor and were asked to perform a series of activities planned in a pre-configured Yolean board through the mobile interface. The tasks included looking up current, late and planned work and updating their status based on information provided in the scenario. Test users were chosen for having previous experience as supervisors and one participant was visited in the field of an active project for testing in a natural environment. An attempt was also made with a participant with no relation to construction projects. However, due to troubles understanding the painted scenario, resulting in deviating focus, it was deemed that a construction background was necessary to ensure the validity of results.

The usability testing did not gather quantitative data, i.e. counting the 'clicks' a user needed to perform tasks. It was rather used to elicit if information was displayed properly and if users understood how to perform the tasks in the scenario which would indicate proper support for the use cases in the prototype qualitatively.

3.5.2 Context Accurate Prototype Deployment

To date, the utilization of Yolean's software for the purpose of production control is by majority being performed in Germany. A German lean construction consultancy firm, running a multitude of active construction projects with Yolean for production control, agreed to assist the thesis project in acquiring test users, translations and communicating feedback from test participants. The fact that these projects were already running Yolean inferred that site managers, supervisors, subcontractors and workers were already used to the Yolean's workflow and the

visualization of projects as daily work notes at their customers' sites, making them prime candidates for the participating in the study.

Testing of the functional prototype was meant to commence in November 2020 but was delayed by the 'second wave' of the Covid-19 pandemic. Live testing began late in the thesis process timeline and direct access to site personnel for test instructions and evaluation was not granted due to confidentiality and language barriers. The evaluation of the live deployment in Germany was therefore done via video chat with the German consultants, summarizing user feedback, and through survey responses. Due to the delays, some iterations of the mobile interface were not tested fully in Germany due to feedback cycles beginning to take longer than iteration cycles.

As it proved difficult to gather reliable data remotely, a project in Sweden eventually agreed to test the prototype in their daily work as well. In January of 2021, towards the later end of the thesis duration, the prototype was deployed at a site performing a re-plumbing project (complete demolition and refurbishing of bathrooms) in apartment complexes already using Yolean for production control. The project was ideal in terms of having a repetitive workflow, and faced complex challenges such as tenants still inhabiting the buildings for the duration of the renovations. The mobile interface was tested by the site manager as well as supervisors and trusted subcontractor representatives for a total of three iteration loops. Before deployment, an interview was held with the site manager (see Section 3.1) on corporate culture, management structure and trust on their site.

Beyond the core prototype, certain functionality attempting to address particular needs discovered during the data collection process was implemented in offshoot versions only, provided to a limited set of projects for testing (Section 5.3). The implementation of these experimental features were for RtD-purposes only and did not integrate seamlessly with the core prototype and the experience it was designed to create. They were not considered fit for a broad release and needed to be explained to users, to avoid confusion, or required certain project configuration to function correctly.

3.6 User Story Mapping

Breaking down the future expected use of a product or a service can tell you a lot about how it will be used and bring understanding of requirements of the product to be designed. Use cases are set up so to map likely situations for the product, and personas help in understanding how different people or roles might use it.

In the early phase of prototype development role based personas and use cases were mapped based on early interviews, observations and literature on the structural role hierarchies on construction sites. The use cases were tailored toward general construction situations the different roles would need the mobile interface in, what their goals with the interaction were, and how they would access or use functional features and information. This was done in order to heuristically map out the interface in theory and to prioritize fundamental required functionality over desirable features.

3.7 Analysis Methods

The interviews, observations and user tests yielded great amounts of language data. To process it all, affinity diagrams, and further the KJ method, were used to synthesize it into something meaningful. Data was analyzed jointly, regardless of data type, so as to start with the broad picture, then narrow down on and find prevailing topics. To keep track of whether data belonged to early or late findings, color codes were applied to data entries to keep track on whether some topics related to early topics of interest or if they had emerged after prototype deployment for the interviewee in question.

3.7.1 Affinity Diagrams

Affinity diagrams were used to group the data, which is typically done based on their "natural relationships" (Balanced Scorecard Institute, n.d.) and finding themes. Common denominators were identified and data were grouped together in ways which could be synthesised to answer the research questions broadly. Language data referring to current production control, organisational structures and roles were synthesised for implications on (RQ1). For data that sprung from user tests or inferring opinion on digital planning and management tools such as Yolean, synthesis was tailored towards (RQ2).

3.7.2 KJ Method

The KJ method can be considered as a refinement of affinity diagramming where language data is condensed and organized into smaller groups. The content is synthesized to a higher level of abstraction (Hallowell, n.d.) to draw accurate conclusions, and strive to yield more post-processing insights regarding things such as cause-and-effects. In this project, the KJ method synthesis has primarily driven the formation of presented themes, as well as the analytic discussion.

4

Findings and Analysis of Interview Studies

The data here analyzed was collected throughout the project from site visits and interviews. The qualitative approach of using affinity diagrams and KJ method seized the relevant intents and meanings behind disclosed information in relation to (RQ1). Usage of general tools for construction management was analyzed along with the usage of Yolean's software, defining personas and use cases for the development of a smartphone application for production control, in relation to (RQ2).



Figure 10: Affinity diagrams.

4.1 Affinity & KJ Method Analysis

This section presents the themes found from the affinity diagrams and KJ method. Insights specifically tied to or resulting from the use of the prototype are covered in sections 5.1 and 5.2.

4.1.1 Site Management & Project Conditions

In this analysis, comments and observations were grouped to distinguish differing responsibilities and perspectives, see Figure 11.



Figure 11: A snapshot from the affinity diagrams.

4.1.1.1 Site Managers

In the construction projects examined by this thesis the site management has consisted of a site manager with at most a handful of supervisors, with the exception of a large and complex infrastructure project which had multiple site managers. Out of the interviewees, both site managers and supervisors, the consensus seemed to be that a site manager spends an absolute majority of their work at the construction site, averaging roughly 75% of the time spent in the site office, and 25% walking the site by estimate. The time varied based on the activities taking place on the site during a given week and if the site managers themselves had to perform time consuming desk work. One of the interviewed site managers was quoted as "Some days I don't even touch the computer, others I find myself asking at the end of the day: Where is my building?" (translated). Another stated that they made sure to try and get at least one tour of the site each day to monitor progress.

All interviewees stated that being out on the site is important in order to stay connected to the project and to understand what the activities in the planning actually comprise and result in. "If you go and look at a torn out bathroom you get a completely different sense of the activity

than if you're just reading notes saying 'demolish bathroom - 4 hours'. It makes you better at planning future activities because you understand what they comprise in reality" - Site manager (translated).

The responsibilities and tasks typically performed by a site manager has been described as follows by the interviewees:

- **Scheduling** - The site manager is responsible for the project progressing according to the time plan and organizes the scheduling as to achieve this goal. In the interviewed projects, this was done in collaboration with supervisors and subcontractors. The format of the schedule and scheduling activities is decided by the site manager.
- **Project economy** - The site manager has the main responsibility for project finances, controlling purchases and ensuring that the project sticks to budget. In some projects, the site manager can be assisted by a project controller who supports the project with fiscal forecasting and takes part in meetings regarding project finances to offload the site manager.
- **Supervising** - The site managers do some of the supervising work themselves as well, especially when it comes to tougher questions and decisions as they carry the overall responsibility on sites. Supervising can include anything from ensuring that workers are using the correct and latest blueprints and are interpreting them in the right way, to evaluating the resulting quality of a job to determine its adequacy.
- **Supply and resources** - Site managers also described themselves checking to ensure that stockpiled material was not running out. Although this task should be performed by foremen and supervisors, we assume this behaviour is due to the site manager knowing that forgetting to restock in time can affect the scheduling, causing unnecessary costs. Realizing that some vital material will run out before more can be delivered would also allow the site manager to be proactive and reschedule upcoming activities if the lack of materials, or them being a prerequisite for other work, is believed to become a blocker.
- **Communications with the project developer/customer** - The site manager continuously updates the contractor on the progress of the construction project, both in terms of financial aspects where budget and time might need to be re-negotiated and on progress in relation to the overall time plan/schedule.
- **Contract changes** - Changes or additions to the construction may arise throughout any construction project. It could be material or minor color changes, or major changes or additions that needs to be re-planned for. It could involve hiring new subcontractors, ordering new material or re-budgeting for the added work.
- **Problem solving** - A big part of the site managers' work is pure problem solving. This relates to all aspects of the job, whether work force is absent due to illness or a crucial material delivery for the site is missing so to not reach a standstill. Some of these events are hard to plan for or anticipate, and there are constantly new challenges for the site

managers to face.

- **Work environment/QEHS related issues** - The site manager has the utmost responsibility for that the site follows QEHS standards and that no one is harmed on the site. Although everyone else has to make sure that they are working in a safe way, it could be the site manager who is held responsible if a preventable accident occurs.

In some cases, such as renovation, civilians might be living or working in the construction area. In these situations, there is extra importance that QEHS problems are dealt with fast, as the safety responsibilities stretches beyond the own workforce.

4.1.1.2 Supervisors

Some of the site managers responsibilities are delegated onto or shared with supervisors. Their role can be described as providing operational support to the site manager and comparatively, they spend a greater amount of their time out on the construction site, approximately 50% according to interviewees. One of their more time consuming tasks is to report near-accidents. Absence of safety rails or if a worker is not wearing protective gear are examples of incidents that need to be reported.

Supervisors are also in charge of the sub-contractors, and are usually the ones managing problems which they may have. They are involved in the workers work in more detail, and in many cases they inspect the workers work and report to the site manager on their progress.

On their many daily rounds they have a good overview of the site, and order trash disposal and material where supply is running short. They also answer "whats, wheres and whens" for sub-contractors and their own work force, so they need to keep up to date with planning and progress constantly. There are usually around 25-30 staff to manage no matter the scale of the production. They all have their trade specific competencies, but scheduling and management of tasks is usually done by, or in collaboration with, the supervisors. The number of supervisors depend on the scale of a project, and they usually divide responsibility for specific subcontractors among themselves.

4.1.1.3 Subcontractors

Subcontractors are hired by the main contractors for specific competencies or assignments. Their trade specific competencies may be required for the entirety or just a portion of the total time of the construction project. Subcontractors who are very involved, sometimes even in the planning phase of a new construction, and who work closely with the main contractor, are referred to as collaborative subcontractors. According to interviewees, these may be more trusted when reporting progress on work and are more self-sustained. Other contractors, especially those only involved with the project for a short time period, may be less trusted to know the routines on the site. Their tasks, as a result of a weaker relation to site management, may require more guidance or to be checked off by a supervisor upon completion.

4.1.1.4 External Factors

Available space on sites is a factor affecting how time specific deliveries and installation of certain goods and products need to be. For rural construction project, there is generally more space surrounding the construction to store and unload deliveries, whereas in urban, highly trafficked areas, deliveries must be made "just-in-time", and installed or taken to their proper place almost immediately (as shown in Fig. 12).



Figure 12: Photograph taken during a site visit, showing the future school canteen being used as temporary storage for goods requiring shelter from the weather.

In the interviews and during construction sites visits, the differences between housing and ground construction became apparent. Supervisors generally tended to lead and instruct more for ground construction. In housing construction, supervisors instead were used to keep track of progress and to support other workers by catering to their material needs or doing clean up for them so that they could move on to their actual assignments. For both cases however, it was expressed that supervisors should not be required to "do any work" if everything progressed as planned.

Interestingly, it was expressed by a supervisor that it is easier to instruct and expect results from a subcontractor than by workers employed by the same main contractor as themselves, this was thought to be due to contractual differences.

4.1.2 Tools & Communication

A lot of the communication on construction sites is verbal. Notepads, note-taking apps or reminders on phones are used by many supervisors in order to remember what they have checked or need to check. One of the supervisors expressed that they were reluctant to use their phone when not absolutely necessary, as it could be perceived by some of their own workers as though they were slacking on the job, but this view was not confirmed by other interviewees. Some coordination and problem solving between workers also happen spontaneously in informal settings such as during breakfast-, lunch- or coffee breaks.

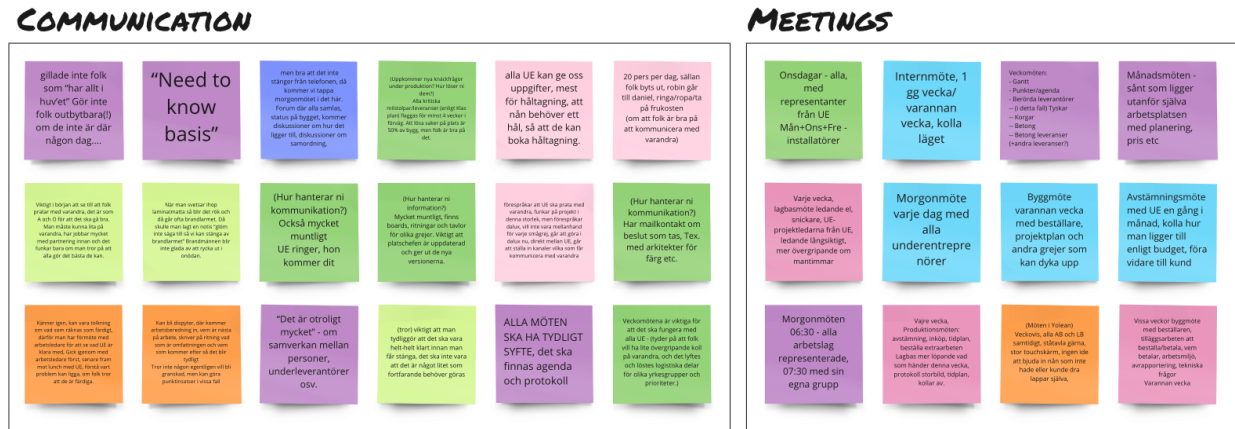


Figure 13: A snapshot from the KJ-analysis.

One supervisor expressed it as being "the be all and end all" (translated) that workers on the site are talking to each other in order for the project to be successful. It is better for the carpenter to go directly to the electrician with a concern about the wiring than that the supervisor is to be the middle-hand. Things are often resolved or clarified more quickly, and it saves time. "There needs to be trust between the subcontractors and they have to believe that everyone is doing the best they can" (translated).

Another supervisor expressed that communication should be on a "need-to-know basis", and that all information should not necessarily be communicated to everyone. However, the same supervisor also emphasised that you should never make anyone nonexchangeable, as that could lead to standstills or confusion if that individual is not present on the site. Important information should per such not be kept in ones head, but communicated or written down somewhere accessible to others.

All sites corresponded with in this study had at the least one weekly formal meeting with site manager, supervisors and subcontractor representatives present where they report on how they are progressing related to planned work, often referred to as *production meetings*. They also used this time to update and commit to the plan for the week ahead. The meeting is a collaborative forum where plans are updated and issues that may have arisen from unexpected events affecting the original plan are sorted out. Every month, or every two weeks depending on site,

Some of the bigger entrepreneurial companies purchase software for project management centrally but only one such case was encountered during this study. Some develop their own to suit needs they have discovered by themselves but have not found digital solutions that addresses them adequately. Examples of this is the Project Portal used by NCC, Sweden's 3rd largest construction entrepreneur 2019 (Byggföretagen, 2020a), which contains tools for coordinating logistics, documenting daily progress in a diary, communicating with the customer of the project and managing contractual changes. Another project, not part of this study but spoken of by an interviewee, had hired logistics consultants who used their own proprietary software for planning. Assumably, in-house solutions like these are developed both as the need for them arises, but also to gain a competitive advantage in procurement.

Generally, each site manager or supervisor appears be free to chose what software they, or the project, prefer to use and can acquire this for the project. In the cases where the study has encountered the use of digitalized documentation it seems to have been mandated by the customer, but the entrepreneurs themselves has arranged for how to collect and summarize it. E.g. the proprietary "Project Diary" used by NCC in the massive project Västlänken to provide the governmental agency "Swedish Transport Administration", who is the purchaser of the project, with continuous updates. In the same project, another example of individual freedom was encountered as the interviewee described how the hired planning consultant had refused to use Powerproject (Section 2.3.3), which was standard at NCC and already been acquired for the project, as the aforementioned consultant had previously worked in Primavera (Section 2.3.3) and decided to use that instead. Assumably, due to the sheer size of a construction project, the financial cost of software acquisition is comparatively low to the overall budget or the potential costs of an unfamiliar piece of software causing inefficiencies or errors.

Although there is some overlap and interchangeability, as in the previous example, different software tools are often chosen for different purposes and for different reasons. Some are inherited from the planning phase before production. These are generally used for visualising the complete time plan of the construction similarly to Gantt-charts. They are, from what this study has found, not used to describe individual activities in detail but generates an overview of milestones and deliverables. The workflow related to this type of software seemingly includes a lot of communication by e-mail as the generated graphs are distributed as PDFs. Often, progress on the plan is then reported back by e-mail in regular intervals and the charts are then updated with this information and passed out once again for the cycle to repeat continuously during the project. See figure 15 for an example of how the visualised output can look as a PDF.

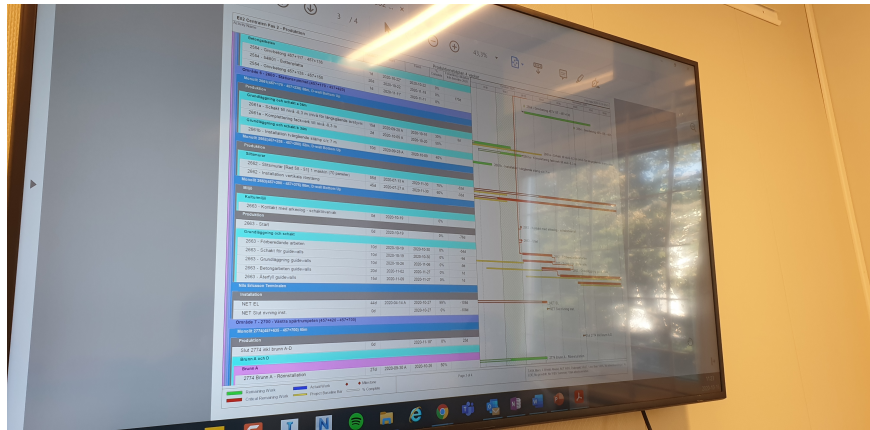


Figure 15: Photo from the pilot field study at Västlänken showing graphs of the project plan and progress.

Other tools are used for documentation of the project, for the case of Västlänken, the Project Diary had to include pictures of the progress, what was being worked on by each team each day, how many staff were present, the weather conditions, etcetera. For another project, a school renovation, similar progress reports had to be made as well but not in such detail or as frequently. The site manager in charge explained that the municipal controller monitoring the project was very appreciative when they received pictures but that it was hard to get the workers to take them. At Västlänken, similar issues with getting workers and all supervisors to write documentation with sufficient detail was expressed. Subcontractors also have to file documentation to certify for different building standards, such as Eurocodes pertaining to structural safety, serviceability or material durability. This is often performed physically where subcontractors attach documents such as material certifications or self-control protocols to folders kept at the site office. Some specialized software was used for documentation which will be passed on to developers for the sake of certificates regarding safety protocols such as fire proofing in public buildings, and for internal documentation.

For note-taking, pen and paper was most frequently stated as the medium. Note- or email applications on personal phones were also mentioned, sometimes connected to a shared online space, or otherwise private. The problems with pen and paper solutions are that the information is not easily shared or accessible to others. Searching for past information is also hard and one could lose notes all together, either among the notes or by losing the physical notes entirely. One interviewee who was about to proudly present their notes-book became acutely aware of this when they could not find it in their bag. In many cases, supervisors also stated that their notes later had to be re-entered into (other) software on a computer. Such examples could be of project documentation, near-accident reports or relaying to site managers to order more materials.

In meetings, construction sites are at varying levels when it comes to digitalisation. At some sites, whiteboards with rows and columns for trades and time are used with post-its to visualize when people will be doing what. These are referred to and used as mediating tools for discus-

sions during production meetings. This was the case at a school construction project visited, where sticky notes were removed and thrown away when the completion of their tasks had been reported. Other sites use large TV-screens (sometimes a touchscreen) to similar display work. Depending on software, functionality of these interfaces differed, with variation in filtering options and ability to show drawings or maps related to the visualised work. At times, they were simply used to show PDFs with bar graphs while at other projects they would display interactive 3D BIM models (Section. 2.2.5.1). Overall, visual material such as blueprints or site plan schematics were frequently displayed as to make it easier to point to what was being discussed. Interviewees all said that visuals like these were an important aid in conversations and during observations their frequent occurrence in common spaces was noticed during site visits.



Figure 16: Photographs from different site visits showing overview schematics taped to the walls.

4.1.3 Yolean in Use

Only two of the interviewees used or had used Yolean software for construction project management in production control. Their usage of Yolean, and type of projects, differed considerably. The currently ongoing project, a replumbing project, had meetings with representatives from each subcontractor every morning and tasks were scheduled on a daily basis per soil stack and floor. The other, which was a new building construction, held meetings in the same constellation but weekly. Here however, job notes could in some cases stretch over several days or weeks, divided into fewer but larger areas on the site. The latter also never had planned more than five weeks in advance in the board, as they argued re-planning work would take too much time if something small changed if detailed planning would be made more long term. Yolean was viewed as a tool to break down the overall project time schedule into manageable pieces and to digitally perform location based scheduling (2.2.2). The soil stack replacement project planned each soil stack about one to two months in advance on a daily level, every soil stack occupying 10-12 weeks in the board. When interviewed, they had already completed the majority of the soil stacks, and so they had continuously learned where the plan may need revision. In both cases, subcontractors added their own work to the board and then the team collaboratively reviewed it for clashes. Yolean's visual planner was based on, and ruled by, the project time schedule produced by project control activities.



Figure 17: A snapshot from the affinity diagrams.

The Yolean board was the focal point in all construction meetings. It visualized tasks as notes and each trade or subcontractor had their own specific colors applied to them. Note status would be 'accepted' when the representative/subcontractor/worker in question committed to a task by personally clicking the 'accept'-option, like a virtual hand shake which the meeting has recognized. Job notes would not be changed to 'closed' until they were 100 % completed.

In one of the projects having daily meetings, only accepted notes were filtered for at all times as the plan was committed to prior to each new soil stack being started. As notes' status were changed to 'closed' (completed) they would disappear from the board, emphasizing the "psychology of not removing incomplete tasks" (translated), as it would be apparent who had not finished all planned work. The notes were closed together in the meetings, making everyone keep track of project progress.

Having the board as visual focus during meetings also made for workers understanding how their work related to others'. It would be clear what work depended on who, both in regards to prerequisites for upcoming work, although the specific functionality to visualize this in the board was not used, and area access clashes. When running into delays caused by unexpected events, work would be re-planned with the meeting participants who would come up with alternate solutions to get the job done, by moving tasks around or pushing a few back or forth in the board, solving the problem together.

Deviation management or methodological root cause analysis was not performed in Yolean in either of the projects. At the soil stack replacement, the site manager stated that "everything planned needs to be done, so there wont be any deviations on notes" (translated). The other site manager expressed that it was too late to put deviations on cards in the weekly meetings, that it would have been something that needed to be done when discovered in the field.

pleted work - "we've already had a lot of inspection remarks that need to be fixed" (translated). They therefore want the final say in when a task is considered complete. This is self-regulating at times where certificates are necessary to certify construction according to national standards, in for example public buildings like schools. Their stamp of signature on the certificates makes liable instead of the main contractor should there be any faults at inspection.

4.2 User Type Personas

Three major groups were derived as being the main potential users of the Yolean mobile application. These were the site managers, supervisors and subcontractor foremen, being the participants on production meetings.

4.2.1 Site Manager Persona

A site manager has the utmost responsibility on a construction site. They report to the building contractor and the project management, who run the project towards the developer. The site manager keeps track on the long-term milestones and deliveries of the construction project as well as that the daily work is progressing and planned for those to be met. A generalized role persona mapping is shown in Figure 19.

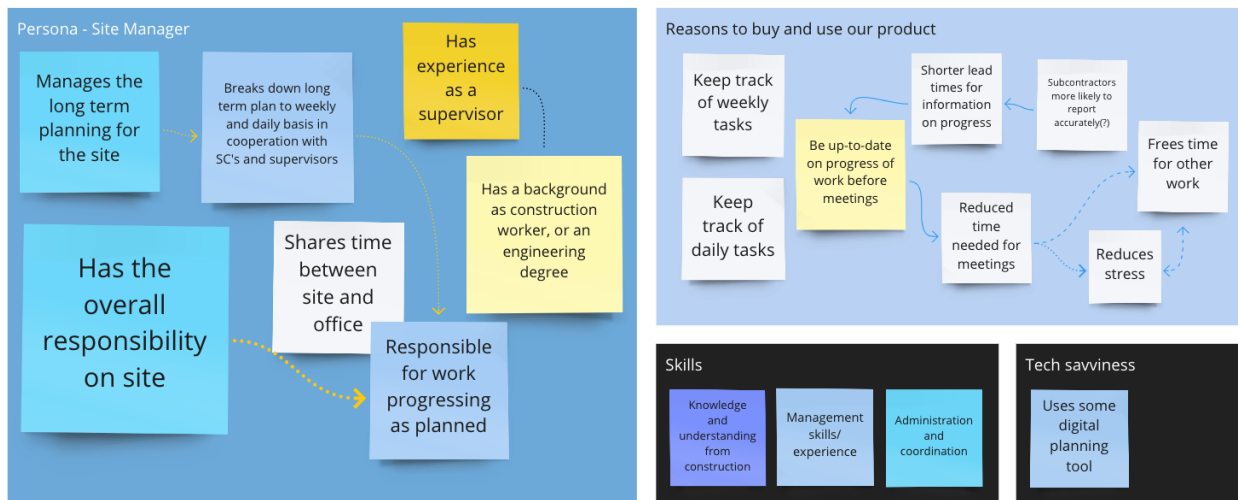


Figure 19: The generalised persona of a site manager

Through being a user of the mobile interface and continually being updated on which activities has been performed or not, uncertainties of such may be eliminated prior to production meetings. Through having supervisors and/or subcontractors updating the status of tasks in real time, the likeliness of the correct information being displayed in meetings increases, and so does the ability of the site manager to base decisions or re-planning on well-founded information.

4.2.2 Supervisor Persona

Supervisors are the link between the performed work and the site manager. They are responsible for that the workers perform the scheduled activities at the correct place, in time, and answers "whats, wheres, and whens" wherever workers may be uncertain of what to do next. Depending on if they manage the main contractors' own workers, or the workers of subcontractors, they may also inspect the executed work and compare it to specifications. Roughly half of their time is spent walking the site and enabling their administrative tasks to be performed without having to return to the office increases their availability. This makes them prime users of the mobile interface. The generalised persona can be seen in Figure 20.

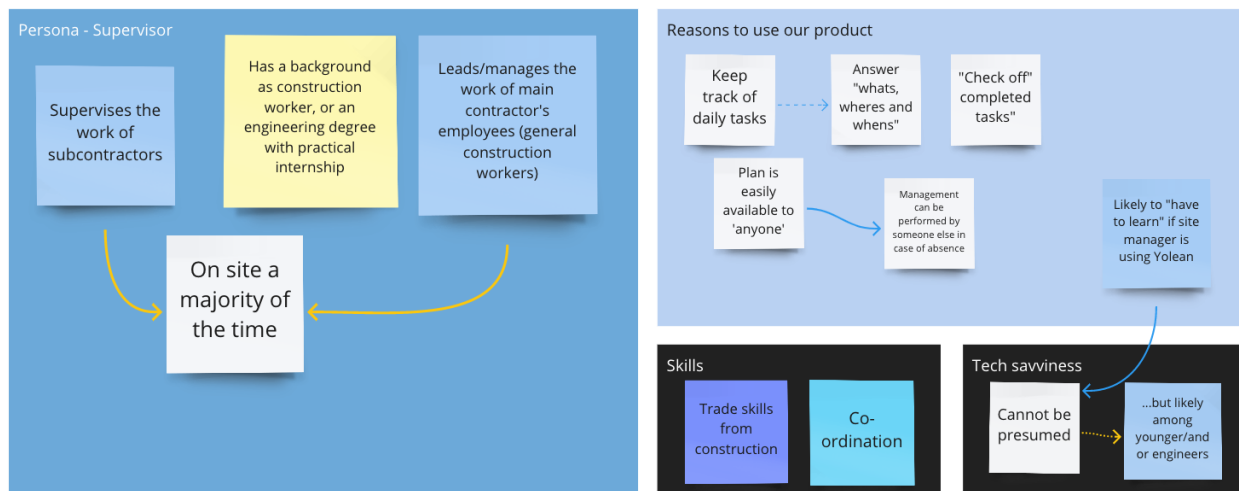


Figure 20: The generalised persona of a supervisor.

4.2.3 Subcontractor Persona

Two main types of subcontractors were identified. The first being a company performing trade specific tasks for the main contractor as ordered and reporting completion to the supervisor(s). The second type being the collaborative subcontractor, which in contrast are more self sustained and trusted in reporting on their own work during production meetings. Subcontractors are generally only interested in their own activities (see Figure 21) and possibly activities that might interfere or clash with theirs'. As subcontractors' trade specific competences might not be needed or scheduled every day, some may be spending less time on the construction site compared to others. This could pose a barrier for learning to use the mobile interface, as it might not be used on other sites. However, in the cases where site management allows subcontractors to close their own tasks in the board, analog post-it boards or Yolean, allowing them to be users of the mobile interface supports them in enabling direct check-off via there phones. This aids themselves, as they do not need to take note of completed tasks elsewhere, as well as site management, as it relieves them of having to inspect or spend time in meetings to close tasks.

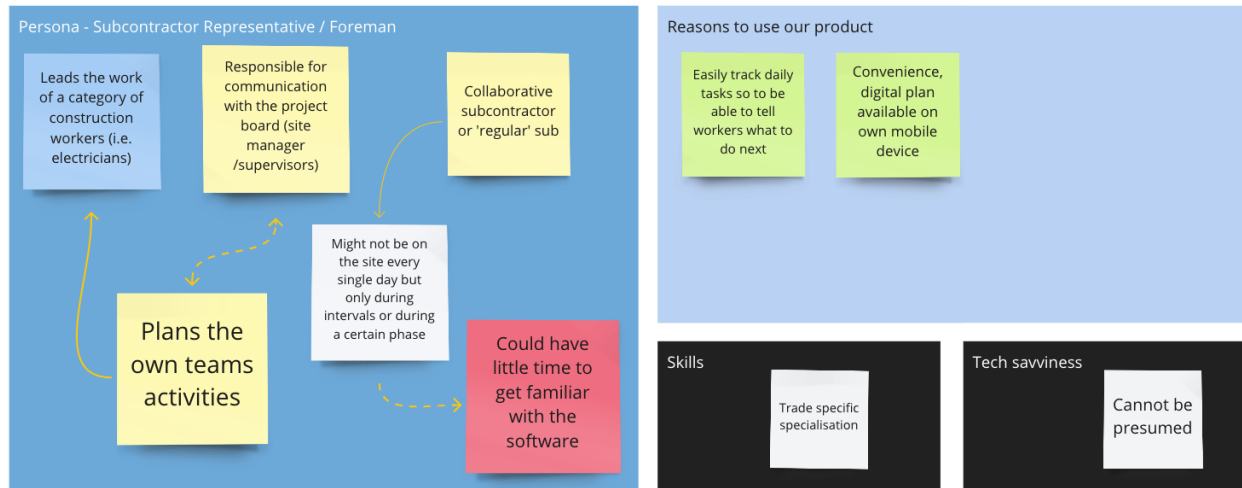


Figure 21: The generalised persona of a subcontractor.

4.3 Use Cases

The use cases in this project (see Fig. 22) are written in a paragraph style, with the user, being the role persona, to support and a probable scenario for their work. This indicates what functionality is required in the product to enable the needed actions.

Weighing the use cases and their implementability through an informal decision matrix, use case (A) was given high priority for the first and consecutive iterations of the prototype as it was deemed to include the key requirements for a basic version of the mobile interface. Use cases (B), (C) and (D) were all prioritized as well, as they rely much on the same functionality as use case (A), making their combined implementation resource efficient. (G) and (J) would automatically be supported by implementing functionality for (A), (B), (C) and (D). Further, use case (F) was touched upon in later iterations of the prototype (see section 5.3.3).

#	Role	Case	Scenario	Resulting benefits
A	Supervisor	<i>Updating the status of Yolean job cards when surveying the site, keeping the Yolean board up to date.</i>	A supervisor is out on the site, doing their rounds. The goal is to check that the workers are OK, and to see how far they have progressed since the morning meeting. The supervisor notes that several of the jobs are completed, and so uses Onsite to close work cards and thereby relays the progress to the site manager.	<ul style="list-style-type: none"> - Site manager is continuously updated on progress as it happens - Saves time in meetings - Supervisor knows which tasks that have been checked and not
B	Supervisor	<i>Reading the jobs in Yolean so to direct personnel of the main contractor to where to work next</i>	As a supervisor is doing their rounds, a worker approaches them and asks what it is they were to do next, they can't remember. The supervisor finds the work cards of the worker and tells them what is their next task(s).	<ul style="list-style-type: none"> - Supervisor does not have to make own lists of what to check
C	Collaborative Subcontractor	<i>Updating the status of Yolean job cards as the activities linked to them are performed, keeping the Yolean board up to date.</i>	A collaborative subcontractor checks the progress of their workers and want to tick off which of the tasks that are ready and which are not. He/she does this in Onsite, both to update the site manager and to be up to speed themselves on what they have left to do.	<ul style="list-style-type: none"> - Site manager is continuously updated on progress as it happens - Saves time in meetings
D	Subcontractor	<i>Checking work cards specific to that subcontractor to know what work to do and where</i>	A subcontractor missed the morning meeting / couldn't participate in the weekly meeting (or simply doesn't remember), and wants to find out what to do directly without having to go to the supervisor. They use Onsite to check what works are planned and accepted.	<ul style="list-style-type: none"> - Subcontractor does not have to make own lists or print from the contractor
E	Subcontractor or Supervisor	<i>Getting an instant job requests in Yolean with possibility to respond.</i>	The supervisor/subcontractor is out on the site and is reached by the information of a new (urgent?) work that needs to be confirmed. The subcontractor/supervisor finds priority in the task and accepts it. They then move to perform/delegate the task. Alternatively, marks the card with a deviation to propose the work should be moved to another available time slot or be discussed in the next meeting.	<ul style="list-style-type: none"> - Communication is immediate but not disruptive (depending on implementation) of ongoing work - Deviations/replanning are (theoretically) more likely to be logged in Yolean compared to if communication was made through other channels and then required additional work to document it
F	Any manager	<i>Adding a question for the next meeting (and receiving a response, secondary)</i>	A manager is out on the site and discovers that the dimensions of a delivered staircase does not match what has been ordered. They want to find out if they should mount the stair anyway and change some surrounding structure or wait for a new one to be delivered. The question is posed through Onsite where they receive the answer to proceed with other work and wait for upper management decision.	<ul style="list-style-type: none"> - The person does not have to make note to remember the question until the next meeting, increases the likelihood of correctly remembering the question - Ensures that the question becomes documented in Yolean along with its answer
G	Any manager	<i>Checking Yolean out of work hours when on the move</i>	On their way to work, a subcontractor is reading up on the proposed weekly planning so as to be prepared for what they need to discuss or re-negotiate during the morning meeting.	<ul style="list-style-type: none"> - Potentially more effective meetings - Convenience
H	Any worker	<i>Viewing the currently assigned work card to find blueprints/documentation of how and where the work is to be performed</i>	A carpenter has been assigned to place fastenings for the plasterboards but is unsure of the spacing. He checks the work card for the room for which he is in Onsite and finds the drawings stating a special case for the room and sets them 550mm apart.	<ul style="list-style-type: none"> - The worker does not need to print or bring blueprint drawings for every work - Convenience/reduced frustration - Interacting with the work card on site (theoretically) makes the worker more likely to note its progress when finished
I	Any worker	<i>Attaching pictures/descriptions of performed work to indicate state/progress and for higher ranking manager to view or to function as documentation</i>	An electrician is pulling wires according to their drawings, but finds that a carpenter has not finished their prior required work. They attach an image in Onsite to their card which is marked with a deviation, "late", to explain why they have not finished on time.	<ul style="list-style-type: none"> - The worker does not have to bring a supervisor over to check on the unfinished work (picture available for all during meeting = mediating tool) - Another platform for documenting progress is redundant
J	Any manager or worker	<i>Checking for upcoming work in the same area/place when one is running late</i>	A painter realises the colors they are suppose to paint that day has not yet been delivered. They will have to paint the next day but wants to be sure that this does not affect another subcontractor/worker who has an upcoming work in that room, in which case the supervisor needs to be informed immediately.	<ul style="list-style-type: none"> - Scheduling clashes do not need to be brought up in meetings, but can be dealt with separately
K	Any manager	<i>Being notified about work that's running late/they are behind on/needs to be checked on</i>	A group of electricians from a subcontractor is performing installations in a large project during a couple of weeks. The foreman gets a notification that work that was scheduled yesterday still hasn't been marked with a state. If the work was already performed the foreman is reminded to mark it as complete, if not the foreman can send someone to do it and create a note showing that it's being handled.	<ul style="list-style-type: none"> - Reduce risk of missed work being forgotten about - Reduces the need for higher managers to spend time on 'laying on top of people' and micro management
L	Supervisor	<i>Checking why a task has not been performed</i>	A supervisor is out on their rounds and notices several tasks have not been performed. They want to check whether the subcontractor has given reasons for this, or whether to tell them it needs to be done. For one of the tasks, they note in Onsite that the subcontractor has marked it with "material delivery delayed", and so does not pursue the subcontractor further at this point.	<ul style="list-style-type: none"> - Easier access to information, convenience - Avoiding unnecessary communication/time spent where there is already an answer
M	Any manager	<i>Being notified that they need to re-plan as an effect of proceeding work not being completed</i>	A carpenter is to fasten baseboards in a couple of rooms which have been painted the day before. The painters realize that the color used was wrong and that they'll have to repaint the rooms. Upon doing so they mark the state of the job card attached to the activity with a deviation and schedules a new job. Due to relations in the Yolean board the carpenter's job now has its status changed automatically to indicate that it can't be performed and Onsite notifies the carpenter about the change.	<ul style="list-style-type: none"> - Saves time as the affected worker does not have to discover the error themselves - Could reduce irritation/frustration

Figure 22: A table over the envisioned use cases.

5

Results of Prototyping and Testing

This chapter covers the functional prototype, its development as well as feedback received by users testing it and the insights generated from these activities.

5.1 Prototype Design and Breakdown

Early conceptualisation of adjusting the existing Yolean interface for mobile (Fig. 23) showed through testing that replicating the existing interface was possible with a low amount of notes but did not scale well with increased project complexity. Text was too small to read and navigation made difficult when touch areas for input were reduced in scale, hence it was decided that a new interface had to be designed.

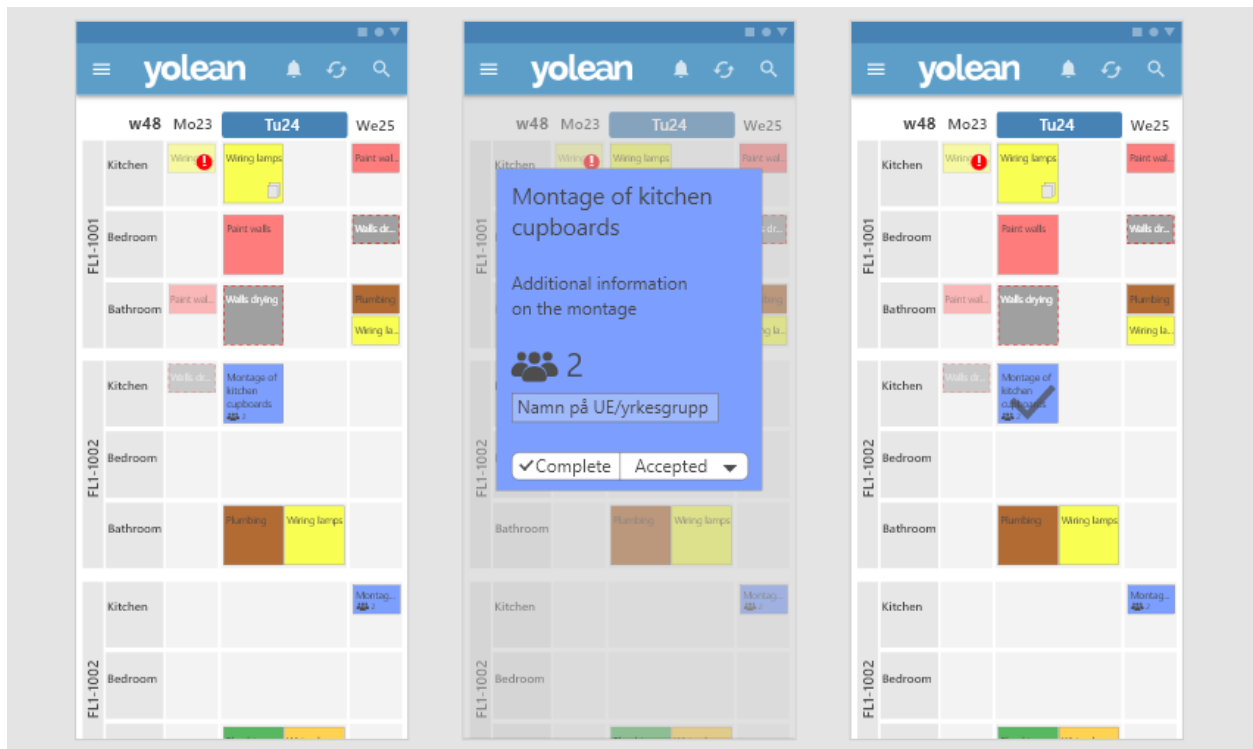


Figure 23: Wireframes of a high fidelity concept of a mobile interface for Yolean's visual planner created early in the project.

For the design of the functional prototype, it was decided to use a strategy of adding as little 'design' as possible, striving for absolute simplicity, due to the following reasons:

- The pilot study and early interviewees all indicated that ease of use was the most important factor for usefulness. Interaction cost had to be low (Section 2.5.3).
- As few sources for error as possible was believed to be important for validity since data from user testing was to be collected remotely. With little to no possibility to instruct test participants, correctly analyzing the sources of errors remotely would be difficult if the interface featured highly complex design elements.
- The strategy reduced the risk of undetected bugs or stability issues which allowed for more efficient prioritization of resources. It was also a precaution to guarantee smooth performance regardless of the device owned by the users.
- As the prototype was developed with a RtD approach, and would be iterated on many times, low complexity was necessary for continual updates to be made smoothly.

It was determined that use cases (A), (B), (C) and (D) (Fig 22, Section 4.3) were to be prioritized and that the prototype had to support them all simultaneously. Through experimentation with different views for visualizing tasks in Yolean (see Fig. 24) it was decided that a list view was the simplest layout option for users to understand, by providing visual clarity (Section 2.5.2), and to implement in the prototype. It was also the most scalable layout, using little vertical space. This was deemed important, considering that knowledge on amount of notes in larger projects was still unknown at the time.

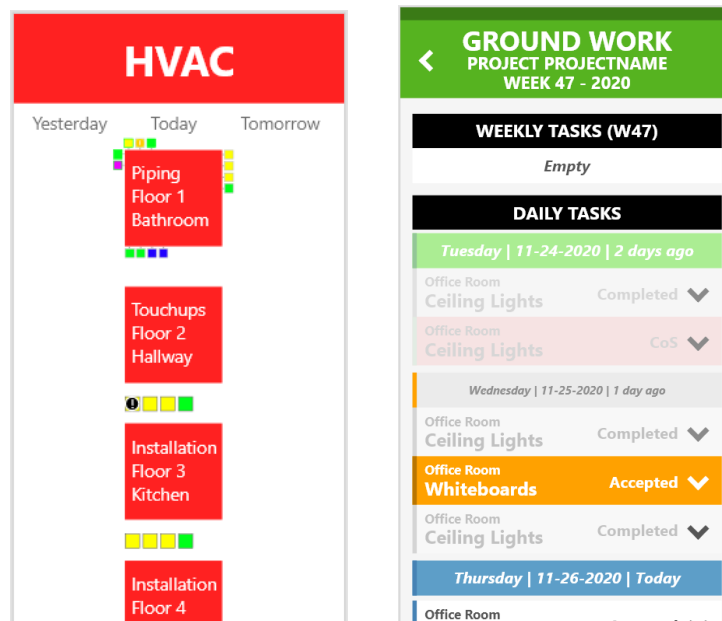


Figure 24: Left: Early concept for visualizing tasks and how they dependencies to other tasks, Right: Early concept of final implementation.

The navigation flow consists of four views where the first two can be considered filter views, the third an item list view and the final fourth being a modal item detail view. These views are illustrated below (Fig. 25) and more detailed descriptions of each are provided in the following sections.

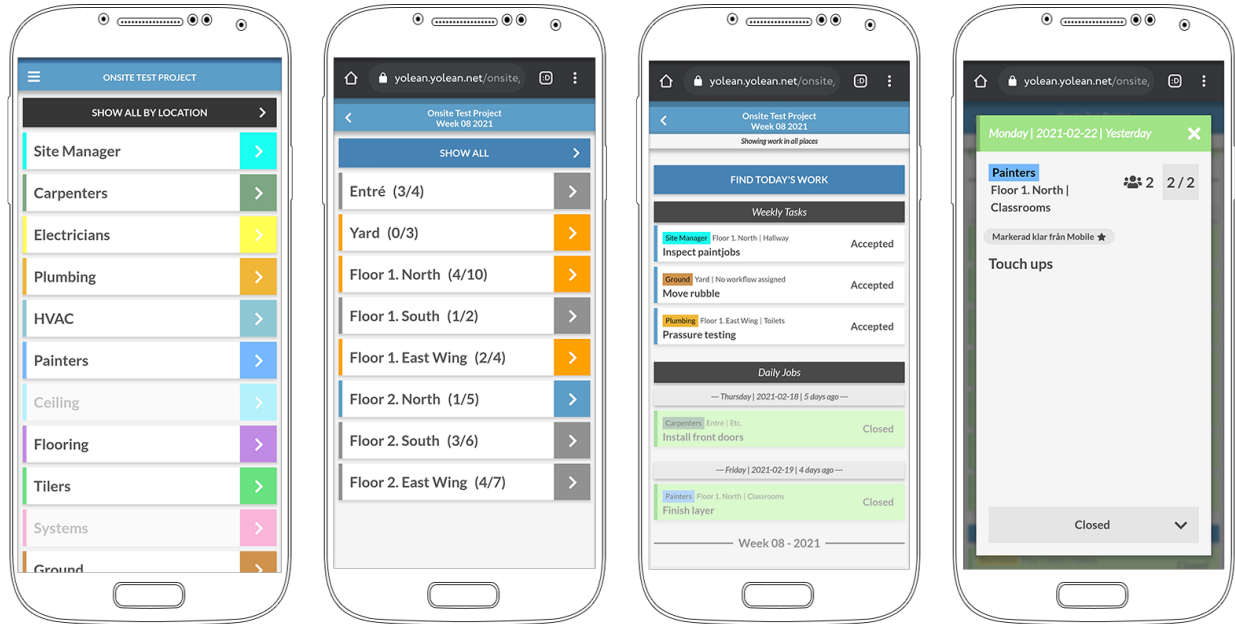


Figure 25: The four views in the final version of the prototype.
 From the left: *Trades Selection*, *Where Selection*, *Notes List*, *Note View*.

It is important to note that the absolute majority of content displayed is user generated, i.e. the project configuration and task data, which results in the software being unusable if the correct content is not there for the interface to display. The terminology used by administrative users (site or project managers) to describe the project and tasked work is crucial to usability aspects, primarily guessability and learnability. If the project lacks configuration or content at all, the first three view states defaults to showing a text telling users that there is nothing to display and *Note View* cannot be navigated to.

5.1.1 Trade Selection

Trade Selection is the root navigation view consisting of a list of all trades that are part of the project (Fig. 26). For the selected use cases (Section 5.1), starting with selecting a trade to filter for relevant content to that trade was determined to be the most efficient path of interaction. As there are use cases where the user wants to view all work in a single location, an option to bypass the trade filter was added through a button at the top of the list as to provide easy access to the feature.

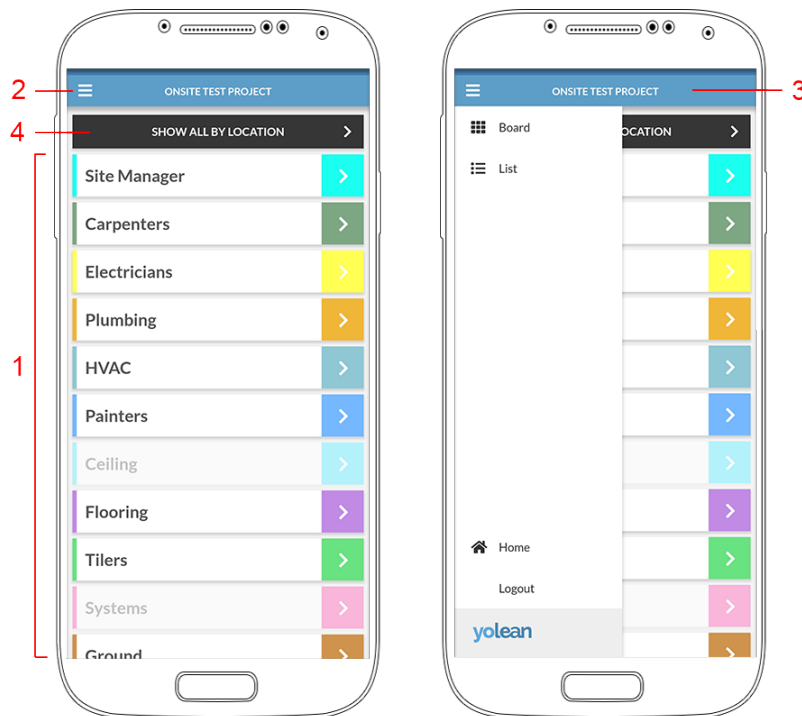


Figure 26: Left: The *Trade Selection* view, Right: The *Trade Selection* view with expanded hamburger menu.

The *Trade Selection* view contains following features, as indicated by corresponding numbers in Fig. 26:

1. The list of trades is the focal point of the view. A chevron icon to the right of each option was added as a signifier to indicate that list items progressed the navigation.

The list elements use the same colors associated with trades in the board view, compatibility (Section 2.5.2), to assist in skimming for specific trades. Instead of coloring the entire element, it was decided to keep each item white for maximum legibility with colors as accents only. At first, it was only added as a contrasting background for the chevron but a thin colored indicator was added to the left of the list item as well to further assist skimming as western cultures having a left to right directed search pattern.

The height of each list item was increased by 25% from its initial value to reduce the required touch accuracy. A shadow effect was added to the list items as a border to contrast the background and visually separate items from each other as to clearly indicate the touch area. A darkening effect upon holding or pressing an item was added as well to provide direct feedback to the user.

Finally, to assist users in understanding which trades had activities assigned to them, trade items without activities were assigned a different styling. The opacity was reduced as to distinguish them from the rest as well as having less of a visual impact on the users.

2. The hamburger menu button was inherited from Yolean's existing product (compatibility) but styled to better match the interface. Tapping it opens a hamburger menu from the left with context dependent options such as leaving the mobile view or signing out. This was a necessity to allow users who unintentionally enters the mobile view to return to the original interface.
3. The project name is listed in the header, ensuring users that they are viewing the correct project as this could otherwise become a source of confusion, especially for users managing multiple projects.
4. To support use cases (A) and (B) it was decided that a method for bypassing the trade selection was necessary and a button to trigger the functionality was added to the top of the list to ensure that users noticed it as they scan the list sequentially. The button was given contrasting colors so to denote different behaviour compared to other options in the list.

5.1.2 Where Selection

The *Where Selection* view (Fig. 27) is similar to *Trade Selection* but lists the project's locations. The functionality is close to identical to the previous view except for an additional layer of color coding to serve as an indication for which locations may contain activities of interest to the user.

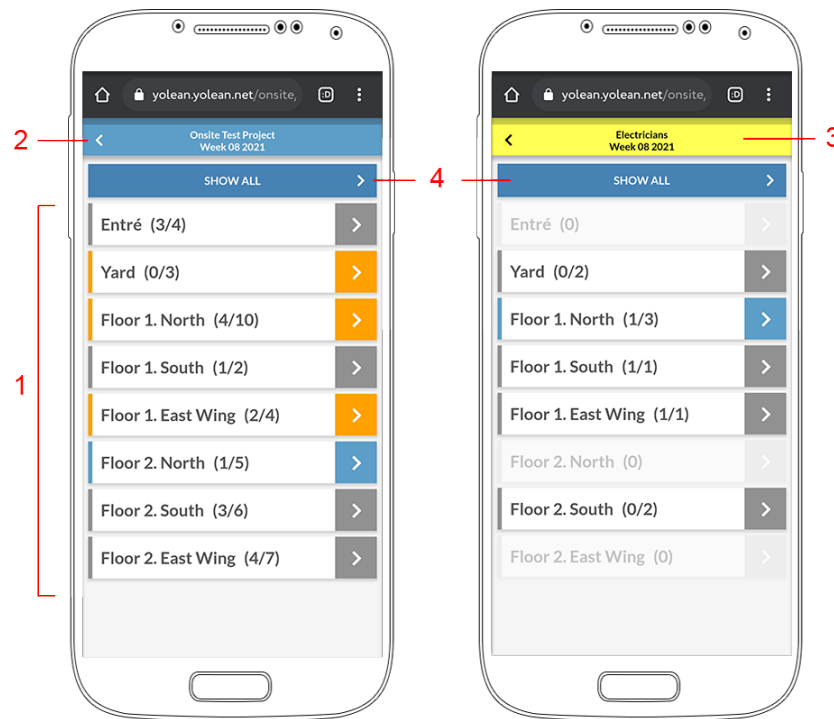


Figure 27: Left: The *Where Selection* view, when filtering for all trades. Right: The *Where Selection* view when filtered for a specific trade, here showing electricians.

The *Where Selection* view contains following features as indicated by corresponding numbers in Fig. 27:

1. The design and styling of the list and its elements went through the same iterations as *Trade Selection* and was updated with additional visual states to assist users in browsing, where contrasting elements default to a neutral grey. Locations including no activities were grayed out with reduced opacity and shading, consistent with *Trade Selection*, although still being selectable as to not lock out a user from ensuring themselves that the option is empty, bridging the Gulf of Evaluation (Section 2.5.1). Each list option also displays the amount of activities it holds, in relation to how many of them have been completed so far, appended to its title.

The additional states, denoted by color, indicates whether a location has activities that are scheduled for the same day or activities that have passed their due date, denoted by blue and orange respectively where orange takes precedence. Additional visual cues for denoting locations with fully completed tasks or task deviations where considered, but

ultimately not implemented as the information was deemed to not be as relevant for usage. More colors would lessen the contrast of the orange, making it harder to see what is of importance, as well as add to the effort needed to interpret the coding.

2. The hamburger button was replaced in this view with a left facing chevron, returning users to the previous *Trade Selection* view .
3. In this view the header displays the previous selection to provide feedback and to orient users if returning to the view at a later time. Bypassing the trade filter leaves the project name and the blue color used by Yolean's graphical profile. If a trade has been selected to filter for, the header instead displays the name of the trade and matches the color of that trade from the project configuration.

The week listed underneath the trade or project title was a legacy feature decided not to be removed as it was thought to ensure users that the correct week was being displayed as well as assisting users in remembering what week it is.

4. Similar to *Trade Selection*, a button to bypass the filter was added, albeit here to support use case (D).

5.1.3 Notes List

The *Notes List* view (Fig. 28) is the target view in most use cases, providing a list of all relevant job notes as filtered for through options made in the preceding views.

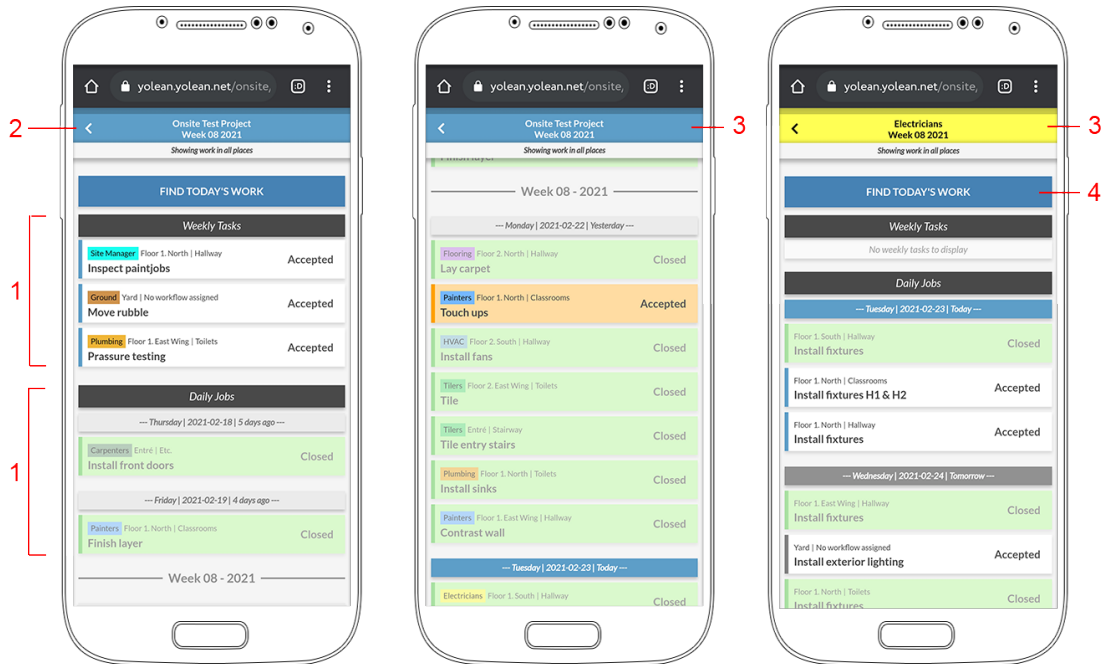


Figure 28: Left: *Notes List* view when bypassing both *Trade Selection* and *Where Selection*.
Middle: *Notes List* when bypassing *Trade Selection*.
Right: *Notes List* with a trade and a location selected.

A legacy feature retained in the first couple of iterations limited the time span for displaying tasks to the current calendar week. This was found to be an issue for several reasons as the complete backlog was not displayed which could be necessary in the beginning of the week, as well as useful during weekly meetings. Not being able to view the activities of the coming week was also an issue for supervisors or foremen wanting to look ahead or, as survey respondents reported, were ahead of the schedule and had to find new tasks for their workers.

It was determined that the optimal time span to display would be from the previous weekly meeting to the next week's meeting, spanning two weeks in total. However, as not all projects had their meeting dates entered in the project configuration as well as due to implementation issues, another option had to be found. A span of the current week as well as the past- and upcoming week, totaling three weeks, was tried at first but found to clutter the list with unnecessarily many completed notes. In the end, a span of the past and upcoming seven days, two weeks in total, was settled on and implemented for the final round of iterations.

Only notes already accepted are shown. The reasoning for not displaying unaccepted notes was based on the view of interviewees that the mobile interface should not replace production control meetings.

The *Notes List* view contains the following features, as indicated by corresponding numbers in Fig. 28 and 29:

1. The list of note elements is divided into two parts, one for weekly- and one for daily activities, each featuring a header telling the note type it contains. Notes in the list are then separated by weekly- and daily separators to show when they are scheduled to be performed. The list is sorted in chronological order from past (top) to future (bottom) so as to having the user sequentially access the information.

Note elements in the list share some visual aspects with the filter options in preceding views but are yet clearly distinguished as to denote the different behaviour where clicking a note expands it into a detail view (*Note View*). Each note contains three fields of information with the first being the content, *summary*, of the note, given visual priority by font size and font weight as well as its leftwards placement in the list item. The other two fields, the location (and assigned trade) and the status of the activity, have similar visual priority. Depending on which filters have been applied, the location descriptor adjusts to only include the information that varies between notes. So that if the user has filtered for the trade electricians at a certain floor, only the workflow of each note is listed (Fig. 29).

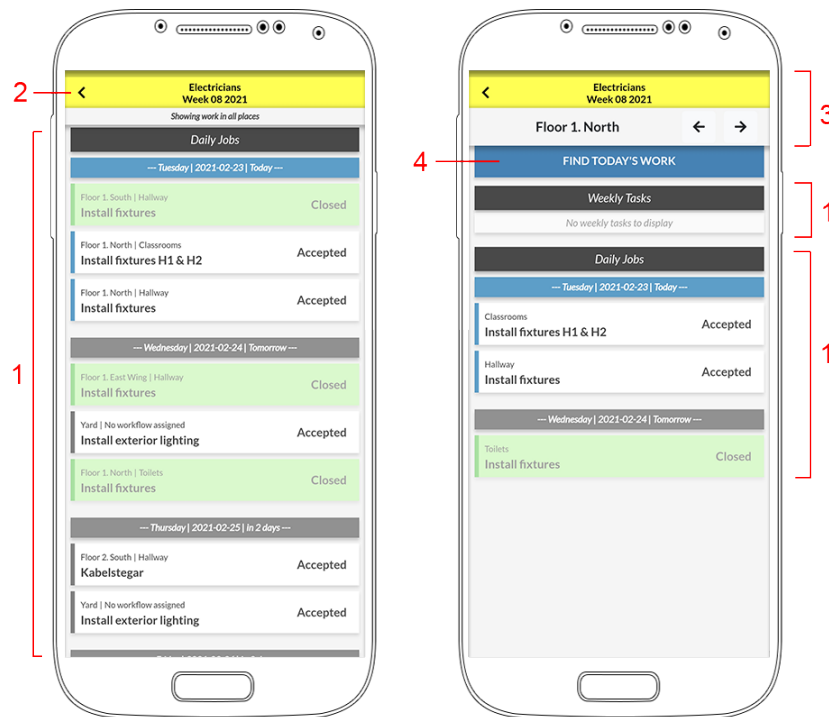


Figure 29: Showcasing differences in *Notes List* dependent on filter options

The status field describes the current status of the task and updates in real time with close to no latency when changes are made, whether from the board view or the mobile interface. At first, the status could be changed by tapping to open a drop down menu, indicated by a downwards directed chevron, but once *Note View* was implemented, ex-

panding the note as a modal, this icon was deemed redundant and potentially confusing for users. To assist in visually filtering the list, color coding was implemented to direct the user's attention. The colors grey, blue and orange respectively denotes accepted (committed) tasks, tasks scheduled for today and tasks overdue, consistent with the coding of locations in *Where Selection*. Additionally, two other styling states, red and green, both with reduced opacity, respectively denotes notes marked as closed with deviation or closed as completed. The opacity fade was as to reduce their visual impact to emphasize what tasks remain to be performed (visual clarity).

The daily separators were iterated upon to include the weekday and relation in time to the current day, decreasing the cognitive load of interpreting dates and reducing the risk of mistaking the weekday of one week for the same weekday in another week. For this same reason, weekly separators were added as well. This was deemed necessary when the time span was increased, partly for the sake of daily notes (see Fig. 28) but also to distinguish the weekly notes by more than color alone. The styling of daily separators was iterated upon several times resulting in light styling where the consistently same tone of blue is used to denote the current day, grey denoting accepted tasks for future days and a light tint of gray for past days to signify their lesser importance.

2. The chevron for navigating to preceding views is presented similarly as in *Where Selection* and takes the user back to that view.
3. The project- or trade name and the current week are displayed in the header identically to *Where Selection*. However, a sub-header is added below to tell the currently selected location, as well as provide buttons for switching between chosen locations. These buttons were a legacy feature but left in as to test if users found them useful.
4. When the option to bypass all filtering and show all notes within the project was added, it brought the potential for users to view extremely cluttered lists as larger projects can have hundreds of notes within a two week time span. To save users who have a need for this view from having to scroll through a potentially large amount of closed notes (theoretically, half of the notes in the list at any given moment should be closed if a project is on schedule), a button to automatically scroll past these notes was added at the the top, similar to the bypass buttons in *Trade Selection* and *Where Selection*.

Instead of snapping the user to the new view, a visual scroll effect was applied indicating to users that their view was simply being moved further down the list, not sending them to a separate view. In shorter lists or if the location only contained past tasks, the button was contextually removed as the functionality became superfluous.

5.1.4 Note View

The *Note View* (Fig. 30) displays all the supplied information attached to the note and allows users to modify the state of the task, marking it as completed or with deviations. This fourth view is not a page of its own but a modal overlay accessed by tapping a list item in *Notes List*. Users can return to the same place in the list when they exit the view and continue what they were doing if opening *Note View* was a mistake or did not accomplish their goal. To inform users about this behaviour, a margin is left where *Notes List* remains visible behind it.

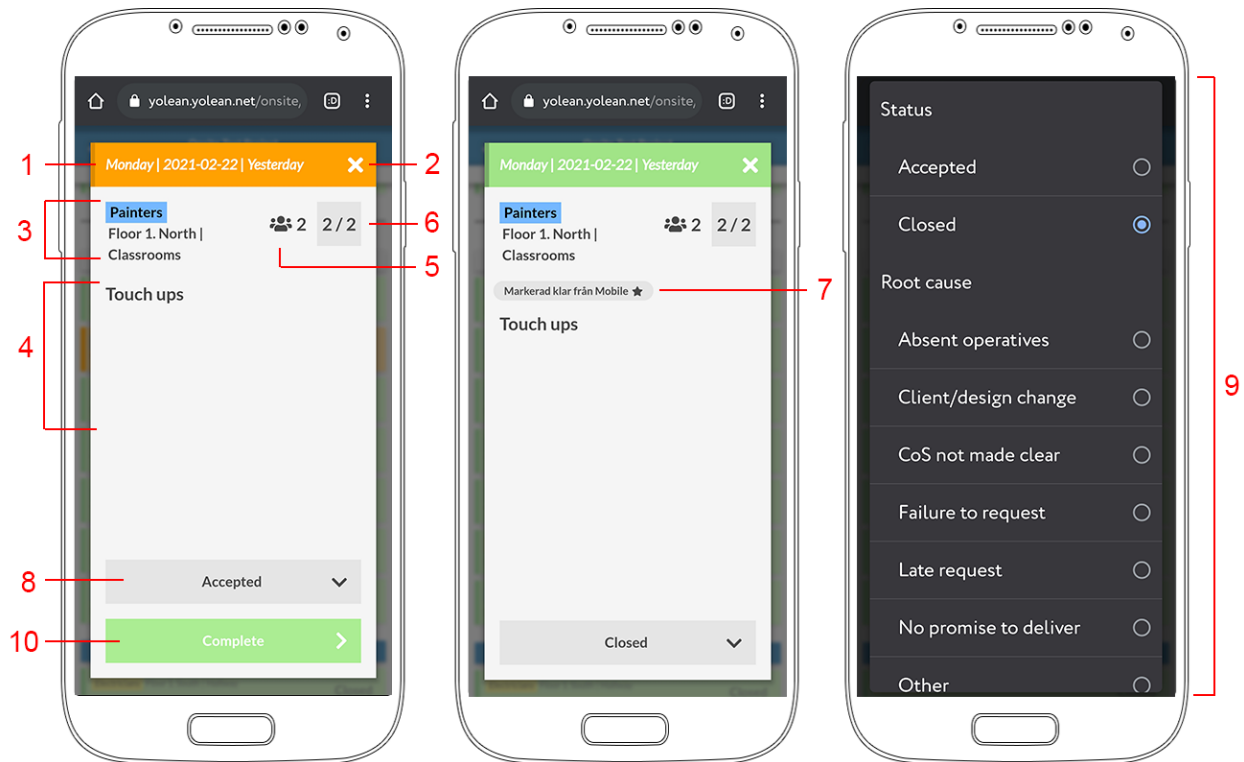


Figure 30: Left & Center: *Note View* with states 'late' and 'completed'. Right: Browser dropdown for toggling states (Android > Chrome > Dark mode).

The *Note View* contains following features as indicated by corresponding numbers in Fig. 30:

1. The header of the note holds information from *Notes List* that should be immediately available - the scheduled date of the task as well as color coding denoting its state (memory load, Section 2.5.3). This can also work to provide feedback of that it is the the correct note being opened. For visual priority, the text is left-aligned.
2. The header also holds a button for exiting *Note View*, closing the modal. The X-icon and its placement indicates that the functionality is different from the chevrons denoting navigation in previous views. The positioning also reduces the risk of users accidentally hitting the button to leave *Notes List* once the modal is exited which could have otherwise been the case if it was positioned on the left side of the header.

3. Similarly to items in *Notes List*, the location and assigned trade is presented at the top of the note. However, in this view all information is presented regardless of previous filters as it is otherwise not immediately accessible (memory load).
4. The note *summary* follows beneath the location, also similar to items in *Notes List*. If a note contains a longer string of words than fits the note, the text box stays the same size but the user can scroll the text within it. Although, the likeliness of notes with such summary length is extremely low.
5. Optional data, such as the amount of workers planned for the scheduled task, is displayed in the upper right corner. If no value for this data has been set, a question mark is displayed to indicate that it has not been submitted.
6. Next to (6.), the note's ordinal is displayed in relation to the number of notes in the chain. For notes that mark one day activities the field simply displays "1/1" to ensure the user that there are no more notes attached to that particular activity.
7. Any labels attached to the note are displayed between the informational section and the *summary*. Labels, configurable in the project settings with a title and custom icon, can be toggled on or off for any given note, defaulting to the off-state.
8. The button cluster, placed at the bottom of the note to be easily reachable with the thumb, holds the state button. This button displays the current state of the task and opens a dropdown element (9.) allowing users to change it.
9. The dropdown is generated by the browser, presumably Safari for iOS- and Chrome for Android devices, which determines its appearance. Selecting an option in the list closes the dropdown.
10. Finally, the second button in the button cluster is the *quick-action button*. This button provides the functionality users are thought to be most likely to want to access, providing a way to quickly mark accepted notes as completed. The color of the button matches the coding for the state that clicking it will result in. Clicking it also exits *Note View* with a brief delay before the note updates so that the user gets feedback through witnessing the change happen as the styling updates.

5.2 User Testing and Feedback

This section covers the findings from testing of the prototype, contextual and live as well as usability testing and when used as a mediating tool during interviews.

5.2.1 Usability Testing

Overall, the usability testing was successful and all participants managed to complete the tasks in the scenario used. The main points at which users needed assistance to progress were due to them not remembering the tasks at hand, as they were only read aloud once during the scenario description. This was not thought to indicate any issues for using the product in real projects, as the user then either is physically at the location where they want to look up tasks, or faced with the trade worker asking for assistance in finding their next task. For the synthetic scenarios, providing participants with written memos was deemed as making the tasks too easy for them, hence this approach was continued throughout the study.

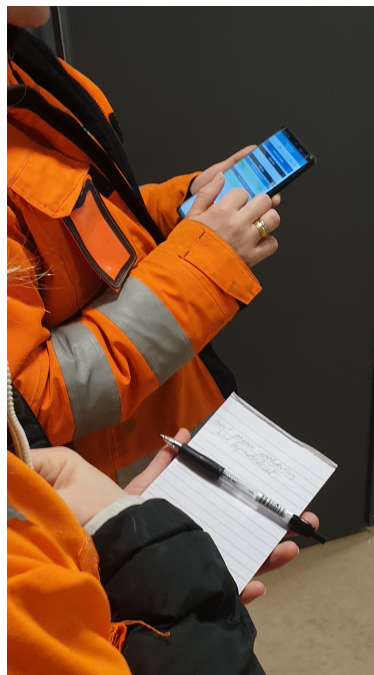


Figure 31: Supervisor navigating the mobile interface during a usability test in context on a visited construction site.

The navigation between the four views (Section 5.1) was easily understood and showed few issues. Some test participants even exclaimed that the mobile interface was more intuitive and easily scanned than the board view in Yolean's existing product. The fact that the interface was smartphone based also received positive remarks as participants claimed to always have their phones with them, and that accessing the board through their portable devices was more natural as it is out on the site where they would like to view their notes.

The current week being displayed in the headers if *Where Select* and *Notes List* was found confusing for some, as it was interpreted as implying that the time span could be changed, confusing the users when they could not find how to do so (Gulf of Execution Section 2.5.1). In later iterations, where the time span was longer than one week, there was also some confusion regarding that notes were displayed outside of the week listed in the header. This resulted in the removal of the week in the header in the final version of the prototype.

When a project contained many notes, or bypass options were selected so to display all notes, the relevant date separator was not always in view, and users found it difficult to know which day a task was scheduled to be performed. Further, the bypass options were not immediately noticed by all users, some even expressed a desire for them before realizing they existed, especially the function in *Notes List* taking them to the current day's scheduled activities. This indicates the perceived usefulness for these functions while revealing a need for increased visual clarity even though the functionality had elevated placement for prioritisation of functionality (Section 2.5.2). Some participants also suggested that the navigation should include search functionality as they were looking for it during the usability tests.

Users easily found *Note View* from *Notes List*, even though the interaction for its access was given close to no signifiers (Section 2.5.1). Test participants were curious if more information would be displayed by tapping the items in *Notes List*, following the same pattern of interaction, consistency (Section 2.5.2), as in previous views. As they all managed to reach *Note View*, its implementation can be considered successful. However, the deviations accessed in the dropdown were confusing for participants. As the listed root causes stem from academia on project management, and default to being displayed in English, they were not perceived as useful or clear to people without knowledge of their theoretical background.

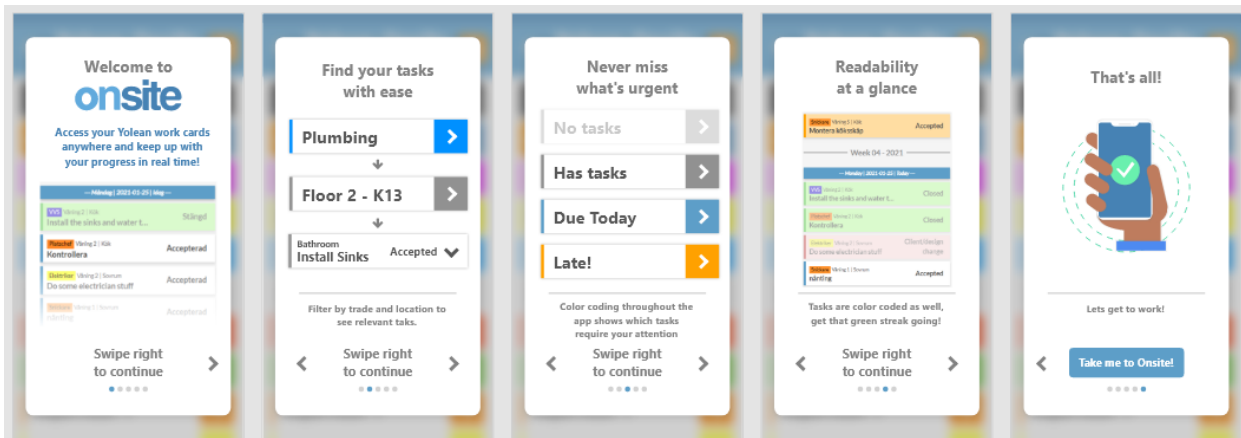


Figure 32: Adobe XD wireframe series emulating an in-app onboarding sequence, designed to be interacted with on a mobile device.

In *Notes list*, the color coding of notes was not intuitively understood, although, when explained it was accepted and considered logical. The guessability of the colors can therefore be said to be low. Attempts on addressing this issue were made through having testers go through an

onboarding sequence (Fig. 32) explaining the four interface views and the meaning of the colors but this, seemingly, did not result any noticeable improvement. However, after having been told what the colors meant, users had no more problems with understanding them when navigating the rest of the scenario, using them to scan for particular notes, so the coding was concluded to be useful overall.

5.2.2 User Feedback

The reception of the prototype among interviewees was overwhelmingly positive. "Why has this not been around before!?" - exclaimed the site manager at the Swedish replumbing project testing the prototype in their daily workflow. They wanted to keep the mobile interface communicating with their board, clearly indicating the need for it. Another Yolean user stated that this is the way one wants to update the board - in the field when finishing tasks or surveying the site. Users without experience of using Yolean were enthusiastic as well, one stating that they would have definitely used it to replace Teams Planner (Section 2.3.2) which had been their platform for collaboration within the the site management team at a large infrastructure project.



Figure 33: Snapshot from the affinity diagrams.

The simplicity of the interface was deemed to be its core value proposition with the available information and functionality of the interface regarded as sufficient for most relevant personnel. Yet, some testers requested features specific to their own workflows (see Section 5.3). Most of these were from interviewees already using other apps for the construction industry, such as Dalux (Section 2.3.4), and compared the prototype against features they were already using in their daily work. Despite this, the amount of features perceived to be "missing" was still very low. These users also expressed a concern of having to use "yet another app" and emphasized that they would require similar functionality to what they were already using if they were to make a switch. This primarily referred to using the tool for two way communication with text and pictures as well as accessing drawings, further covered in Sections 5.2.4 and 5.3.3.

Using the mobile interface required some adjustment for users already familiar with the Yolean board as it does not display notes in lists, but after a few moments it was easy to see the connection to the board. One site manager reflected that the mobile interface would be more ac-

cessible to workers, who do not spend much time in planning software, and that the view is more legible and simple to access. This view was shared by the German managers, one saying: "the intuitive navigation workflow" is good for when instructing workers on tasks while another agreed saying it was "easy to understand, even for the trade workers [who do not regularly see the Yolean board]".

Many interviewees had opinions on the landing page of the interface, should all workers be allowed to access it and not just the stipulated role personas, as the natural landing page would arguably be the view of their trade. They correctly identified that the interface was designed for multiple use cases and user groups, one tester stating "If you're a site manager, you want to start with viewing work for all trades, if you're a subcontractor, your start view should be that of viewing your own tasks".

The color coding, although not completely intuitive as shown in the usability tests (Section 5.2.1), was considered good for determining what to prioritize when quickly scanning the interface for tasks. Additionally, a Yolean user who had previously never used the deviations with root causes due to it being "too late to mark deviations during the weekly meetings", stated that they now saw great potential for their use of the product in future projects. This example indicates that the mobile interface enables functionality which previously has been unusable due to contextual circumstances.

Who should be allowed to use the mobile interface to view and change status of notes was a complex topic, and generated contradicting statements, when probed for in interviews. Generally, managers were extremely positive towards the idea of increased collaboration but were hesitant of granting access freely, as they did not want to lose the full control they are used to experiencing with existing systems. Many wanting to see variable settings for access to collaborative functions so to tune functionality by what is suitable for their project and organisation. One supervisor viewing this as a way to dial in to an appropriate level by testing. Some managers were scared that subcontractors would delete notes with activities that they did not want to perform (not possible from the mobile interface) or close notes with uncompleted tasks.

5.2.3 Insights from User Testing

The live user testing highlighted some technical difficulties. Connection to the server was frequently lost if the browser tab had been exited and then reopened. Users would sometimes have to re-establish their connection by clicking a pop-up as this did not happen automatically. When 'offline', the web app remained usable and items were still clickable in the lists. Generally, this is not a huge concern, but it could be problematic if changes to notes were not relayed to the server nor displayed as expected. The action of refreshing, when not required in order to reconnect to the server, was in itself also an issue at times. Users may have a mental model of that web pages need to be refreshed to update, and though the mobile interface did not require this, users did it from habit even when informed. This caused unnecessary refreshes, resetting the page, and triggered bugs with certain features of the prototype.

If the link to the interface was saved on the home screen of a device for quick access, a new

tab would open in the browser every time it was triggered. This is also not a huge concern, but could become an annoyance for people who access the web app frequently as they would quickly have a large amount of open tabs in their browser which they later needed to close.

Language barriers and device availability proved to be unexpected hinders. Swedish sites generally prefer interfaces being in Swedish, as English proficiency among workers cannot always be expected. However, there are international work forces on some sites whose English proficiency is also low, for which Swedish nor English would be the ideal language, and Yolean does not currently support users setting their own preferred language. The interface also relies on users having their own devices with internet connection. Not everyone are supplied with one from their employer and cannot be expected to use their private devices. This caused issues for site management to get subcontractors to test the interface.

The German consultant firm and their participating customers had concerns for allowing workers to test the interface at all. Primarily, these regarded workers accidentally rearranging the scheduling when viewing it (In some cases, this seemed to be based on previous experiences of bad actors) and the effect of workers being able to view other trades' notes. It was feared that this would lead to conflicts between workers, one blaming another for being the cause of the project stalling. Viewing this information should have already been possible in the Yolean board during meetings, but color coding and easy filtering in the mobile view was perceived as making it increasingly evident if workers from a trade were not progressing their tasks as scheduled. This inherent feature of the interface is in itself in line with LPS (Section 2.2.4), providing measurable and easily understood indications of performance. However, there are merits to these concerns, as data needs to be interpreted to determine the actual root cause, an activity trade workers lack training and experience in doing. Blaming someone with a red and orange list would always be the easy interpretation and to avoid conflicts altogether it was insisted that the view should be locked so that subcontractors could only view their own trade. As Yolean does not link a trade to their users' accounts, this was not possible to implement in a feasible manner and a complete lockout was impossible to achieve. Handing out individual links, taking users directly to the *Where Selection* view of their trade, could potentially have been done, but was thought to raise barriers for testing as it would have required more effort from management of the test sites to distribute links. A workflow they were already complaining was too bothersome.

When probing Swedish interviewees on this issue, some agreed that this concern had merit. One Swedish supervisor participating in the usability study argued that they would give access to, and permissions in, the mobile interface to everyone on the site. They would then work with creating routines and good attitudes for closing notes instead of locking people out. That workers could see each others' tasks would ease collaboration and reduce time which the supervisor had to spend coordinating subcontractors. However, settings to limit some subcontractors permissions were still desired so to keep the power on deciding when a task is completely done (as elaborated on in Section (5.3.2)). Seemingly, the culture and levels of trust on a site affects how willing management is to allow access to relevant users (Section 4.2), however, the prototype represents a commercial product and had to be developed on the premise that sites strive for efficient planning and cooperation.

Despite the reluctance to performed agreed upon tests, the German survey respondents reported having tested the mobile interface for several days, indicating a discrepancy in the communication. Additionally, the consultancy firm demoed the mobile interface to potential customers with positive response, inferring it adds commercial value to Yolean's product.

The Swedish replumbing site testing the interface reported that subcontractor supervisors, on their own initiative, began using the interface to relay tasks to their workers by taking screenshots of the interface on their phones and sending these to their workers. This behaviour is interesting as it confirms aforementioned issues of having to copy information from one format or platform to another and infers that the mobile interface now found to be the most efficient way of relaying information from the Yolean board to workers. It also indicates that the information in the notes, at least in this project, is of use to trade workers. However, when the site managers was asked if they would like to have all workers interacting with the interface in the future, the answer was still reluctance. They thought that trade worker would have a hard time understanding what notes meant or which were relevant for the specific worker.

Another interesting behaviour noticed at this site was how they did not use the deviation statuses but left unperformed tasks with corresponding notes still accepted, then closed them once they were completed. This was proudly motivated by that "All work on the board has to be performed, we can't leave anything out". This indicates a perspective, assumingly shared by the team, of viewing the job notes as representing deliverables, not activities. Whilst the concept of deliverables is well established within fields such as design and product development, none of the interviewees recognized the term and many mistook it for the delivery of goods when this topic was probed. The lack of this concept in their terminology resulted in, in the view of the authors, misuse of the Yolean planner, being designed to function as a planner or calendar, not a to-do list.

When analyzed, this workflow results in the Yolean board no longer being an accurate description of how work has progressed and KPIs become misleading or completely false. The project will seemingly have stayed perfectly on track with a 100% PPC rating as long as workers catch up (2.2.4), losing its value as documentation material in retrospective learning sessions for continued performance improvement.

It should be noted that these issues seemingly do not stem from the usage but are inherently caused by the design of the tool, which is simply not a perfect fit for users performing production control. A project using the functions as indented, i.e. either closing work or marking with deviations if it was not performed, would face other issues in this same scenario. If the cause and effect of a deviation is simple, e.g. the absence of workers resulting in no work being performed, the design is sufficient, but in more complex cases, e.g. work being more complex or requiring more resources than planned for, the binary states of the note are not enough to accurately describe reality. The current implementation of deviations implies through its signaling that the activity has not been performed. This should make personnel prone to mark work taking longer than planned as closed, then adding another note for the next day. After all, they have performed work where and when they were contracted to, there being no deviations from the schedule from their perspective. The board would then accurately reflect how work

has been performed, i.e. the status and time slot of each task is correct, but would still have KPIs being potentially misleading as additional job notes were added. In a worst case scenario, constantly adjusting the plan like this in order to match reality could also make for a 100% PPC rating even though the original plan was not accurate, making it hard to detect and learn from the issue. This conflict of perspectives seemingly results from having production workers interacting with the tool. The coding for deviations, both in terminology and graphical indication (an "X"-icon in the board view or red in the prototype of the mobile view), makes sense from the perspective of the planner, regardless of root cause. However, from the perspective of the one executing the work, if the work has been performed as ordered the coding should expectedly indicate a positive result, instead of being visualized as an error.

With all of this said, the replumbing project still claimed to analyze and learn from progression of the schedule in previous phases, having identified repeatable workflows (Section 2.1) and adjusting the scheduling for each new phase to make work more efficient. The site manager also mentioned the use of some metrics for this purpose, including PPC, making the described process similar to the learning process as described by LPS (Section 2.2.4). These metrics were seemingly generated by project control instead of obtained through Yolean.

5.2.4 Requests for Features

When requesting features, interviewees naturally referred to functionality that would be useful or fit in to their existing workflows. The following are excerpts from the features users require or want in the mobile interface.



Figure 34: Snapshot from the affinity diagrams.

Adding Photos and Comments

Being able to add photos and comments on notes was considered to be practical and necessary for communication. It would allow for better understanding and control of performed and non-executed tasks without the site manager or supervisor having to physically be at the location for inspection. A tangible example was observed during a site visit where carpenters could not finish the installation of kitchen drawers as these were too deep and would interfere with the sink pipes. Explaining the exact issue and motivating why new drawers had to be ordered though text alone could have been tricky but could easily have been explained through a photo attached to the deviating note. The mobile interface would be especially suited for this task, as an absolute majority of modern mobile devices feature cameras. Photos would also serve as confirmation when closing notes and could further be used for documentation to be passed on to the client in cases where such were desired. These requests resulted in an experimental feature, see Section 5.3.3.

Drawings

Having drawings available through the mobile interface was also requested. An electrician, briefly interacted with during a site visit, made annoyed gestures towards a makeshift desk overflowing with wiring diagrams (Fig. 35) and exclaimed that he would much rather have them digitally. This view was shared by interviewed site managers and supervisors, although not the electrician's superior who preferred papers to scribble on, and indicates that it should at least be possible to view drawings through mobile devices for those who wish to. One site manager interviewed whose project used an app where workers could access documents such as drawings claimed that this functionality was extremely appreciated by trade workers.



Figure 35: Makeshift desk with blueprints photographed during a site visit.

Form Factor

Several of the sites interviewed had tablets for note taking and documentation during inspections, and other expressed a desire to include tablets in their workflow. In Germany, some sites used the Yolean board on tablets already, but did not find it to be optimized for the device. In-

interviewees would have liked to see the mobile interface adapted to support the tablet screen size as well, and one site manager suggested that the tablet format of the interface should be that of the Yolean board mixed with some of the interaction patterns of the mobile interface. As this was outside the scope of this thesis, no attempts on developing an interface for tablets were made.

Altering the Time Span

The finally settled upon time span of displayed notes (Section 5.1.3) was sufficient according to most interviewees. However, some wanted to view notes further into the future at times, both for when their workers were ahead of the plan, or when stalled from doing scheduled activities and needing to find other work to do. Out of the German form respondents, several independently asked for this feature.

Hiding completed notes

Similarly to how the Germans were interested in viewing more notes into the future, they also commented that past notes which were already closed were of little interest to them and that the ability to hide these would be welcomed. This is somewhat in line with the usage of the Yolean board view at the Swedish replumbing site where the filter was set to only show accepted notes, resulting in that closing a note caused it to be removed from the view. A similar mindset was described by the site manager as motivation for using this filter, claiming that it was only interesting to view what work remained to be done, the other being a distraction. This preference might have some correlation to the user's position at the site. As many of interviewed supervisors left positive remarks on the how completed tasks were visualized in the interface, saying that it added to the sense of accomplishment.

Support of Trade Worker Management through Yolean

Similarly to how subcontractors on the Swedish site testing the prototype used screenshots of notes in the mobile interface to relay tasks to workers, the feedback from the Germans received through forms indicates similar thoughts where several respondents referred to how it was good that "even trade workers understood the simple interface". One German site manager implied that they would be interested in trying to direct workers through the mobile interface, leaving a suggestion that "if start times of cards were clearly visualized and sorted by, the workers could be shown the sequence of activities".

Options for Complex Filtering

Although one survey respondent found the current filtering options to suffice, the rest all wanted the ability to filter by several trades simultaneously. This request was also expressed by some Swedish supervisors with background in ground construction projects. Within these types of project it is seemingly common with a supervisor managing a set of smaller subcontractors, perhaps even without foremen of their own. Another scenario was where a larger contractor would have several internal teams, dividing work among themselves. Both of these use cases called for more complex filter settings, the first requiring the option to select multiple trades to filter for, preferably as a saved filter preset. The second had a German site manager suggest the ability to filter by label, inferring that this was how they distinguished which teams within a trade had been assigned tasks in their current workflow using Yolean.

Adding Notes

Although the implementation of the mobile interface as a tool for displaying committed scheduled work only was generally accepted, interviewees and survey respondents still believed that there could still be times one would like to add notes. One example given was when a task deviated and they wanted to reschedule the activity right away, another was to update the board with additional work that had to be performed. Similar functionality exists in Dalux (Section 2.3.4) and interviewees using it reported it being an efficient way for workers to collaborate through receiving tasks from each other. Through this they performed some of the problem solving otherwise done in production meetings themselves, relieving managers and shortening lead times.

Delivery Schedule

Reception of material deliveries on sites is a complex problem in itself, and interviewees were probed on whether this was something they would have liked implemented in the mobile interface. The interest was tepid, and site management was generally content with how their current delivery schedules worked.

5.3 Experimental Feature Testing

Beyond the prototype, additional features were implemented in experimental stages to address certain needs discovered during the study which were deemed to be of interest for (RQ2) as potential value providers. The experimental implementations aimed to evaluate this through user testing and to generate further insights.

In contrast to the core prototype, which was created to provide a simple but solid experience, the experimental features were developed for the sole purpose of evaluating their functionality during controlled periods or sessions. As they were not already supported by Yolean's product, the limitation of only being able to alter the client-side application required creative solutions and workarounds to simulate the behaviour of the envisioned functionality. The design of these implementations should be viewed as branches for the purpose of research only, and not be considered as parts of the prototype concept.

5.3.1 Meeting Mode

Motivation

One commonly asked question by both interviewees and user survey respondents was why the interface did not display unaccepted/forecasted tasks. Although the reasoning behind this was often accepted, the opinion that it would be useful to display and accept these notes was shared by many. Methods for enabling this functionality without risking to void the concept of commitment meetings was ideated upon.

Through concept selection it was decided to implement a way for activating this functionality during meetings only, as this context was thought to be the main beneficiary from it. The hypothesis was that the feature could serve as a fallback method for meetings where participants could not be made to, or were restricted from, performing the physical action of clicking

to accept the note on the board due to e.g. unwillingness, time constraints or social distancing measures. Additionally, the situation could serve as an onboarding context where users got comfortable with using the product in a controlled environment along with colleagues. Present managers have the possibility to monitor and assist in the process, ensuring hesitant managers that they still remain in control.

Implementation

Preferably, the feature would have been triggered through the board view by the meeting moderator or automatically during scheduled time slots. Instead, a workaround found was, as modifications to the desktop interface were not possible, using a note to hold configuration data and updating it through changing the state of the note. Enabling the mode by toggling the note to 'accepted' changed the behaviour of *Notes List* to also include notes for unaccepted tasks (Fig. 36).

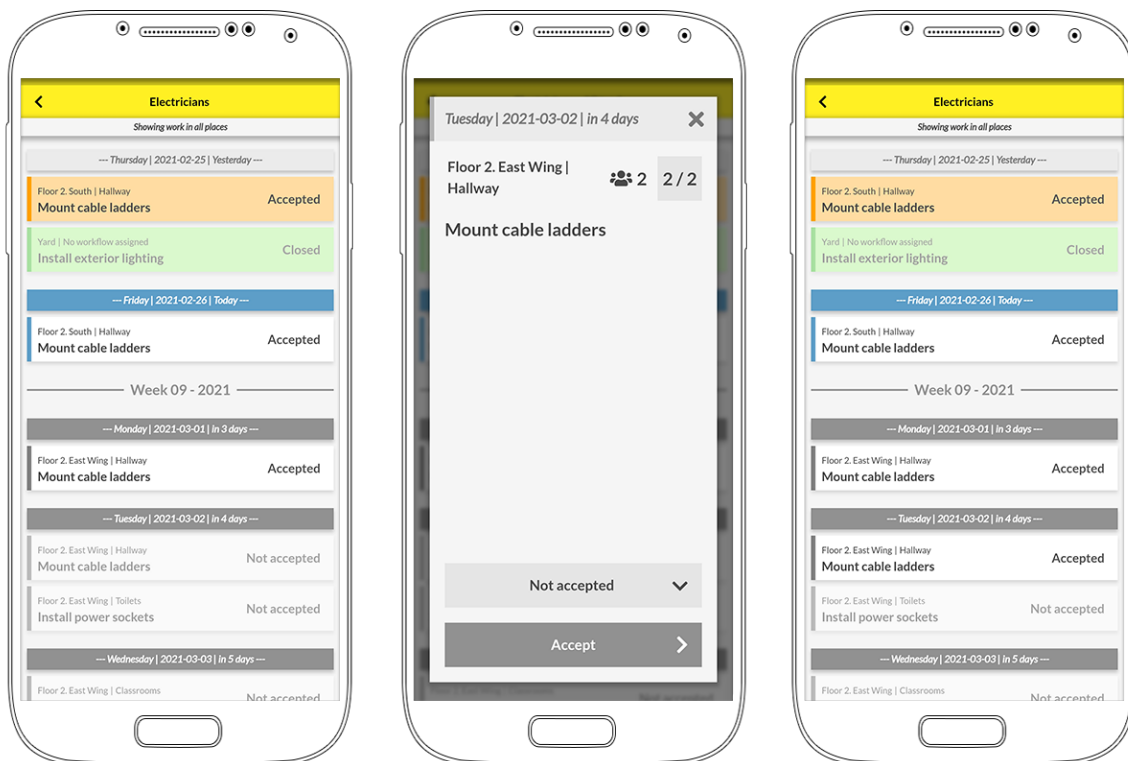


Figure 36: Showcasing how the interface adjusted to support *meeting mode*. Left: *Notes List* displaying unaccepted notes. Center: Unaccepted note in *Note View*. Right: *Notes List* updated after accepting the task.

The unaccepted tasks are displayed in *Notes List* with similar styling to accepted tasks except for an added opacity fade. This mimics how unaccepted notes are displayed compared to accepted notes in the board view (compatibility, Section 2.5.2), visually separating the two. The *quick-action button* here contextually updates to provide the option to quickly accept the note without having to access the dropdown or manually exiting *Note View* after each commitment. Once the mode is disabled, any unaccepted notes remaining are once again not displayed in *Notes List*.

Test Results

Testing of this feature was difficult, as it relied on a German consultant company to be the middle hand for relaying information to the testing sites. Management were reluctant to grant access or hand out the link to the mobile interface, although whether this hesitancy came from the consultant firm or site management could not be determined.

Usability aspects of the implementation were also questioned, understandably, but it was hard to determine if this was an actual blocker or simply a way to stall until the wanted restrictions were implemented. In the end, all of this resulted in testing getting delayed into the infinite, though several attempts to offer direct guidance via video were made.

The meeting mode was not tested at the re-plumbing site in Stockholm either. Their workflow was based on sprints where notes for entire soil stacks were accepted and committed prior to each new stage, utilizing phase- and look ahead planning similarly to how described in LPS (Section 2.2.4) but only re-committing to changes. Ultimately, they already had an active culture of all participants interacting with the board which they perceived to be valuable, hence being a bad fit for testing the feature.

Finally, the German consultancy agreed to test the feature in their internal weekly meetings to assess its potential. They enjoyed using it, and found it to be a good view for participants to interact with the board during video meetings. They still had complaints about the implementation, as to be expected, and encountered some light bugs forcing some to refresh their browsers. A feature request resulting from the feedback, that could be considered valid regardless of the difference in context, was that users would have liked to have their KPI statistics displayed in the interface during the meeting. However, this functionality is not easily accessible in the board view either, which may be the reason for this need surfacing, as well as all of the participants being lean specialized managers by trade.

5.3.2 Completed-not-Closed

Motivation

Due to the at the time existing implementation of user groups and permission handling in Yolean's platform, users either had no access, access to viewing only (this was the most common for subcontractors) or complete access to viewing and editing. The implications of these restrictions were that projects were not leveraging the collaborative functionality Yolean offers, missing out on a large part of the value the service aims to provide. The benefits of having the board with them in the field were gained, but users would still have to remember what notes to close until the meetings. Additionally, functionality developed in the prototype, such as color coding, risked becoming unusable or potentially misleading if tasks statuses were not being updated.

Further, there are additional problems with attempting use of Yolean's product in the field as the selection of statuses do not immediately fit for matching all possible states of work in the real world. Issues arose on how one should mark a task that is nearly completed, but not fully, or if more work than anticipated was needed and additional work still remained although the

scheduled work had been performed. A similar dilemma was how to mark the state of tasks that had been performed but would need to be inspected by a supervisor responsible for its quality. It was also stated by multiple sources that they considered it hard to perceive changes in the board if they were not present when the change was being made.

Implementation

To address aforementioned issues it was decided to, as a first step, implement an additional state for tasks. This state was to be named *completed* and would function as a step between accepted and closed, replacing the closed option in the mobile interface. As Yolean did not support custom states, a workaround was found where a custom label acted as a completion marker and was applied to notes when marking them as completed. Accepted notes with the completed-label were then interpreted as having a completed state in the mobile interface and received the styling of closed notes. In the board view, these notes were still displayed as completed but with the label denoting that they had been marked completed from the mobile view.

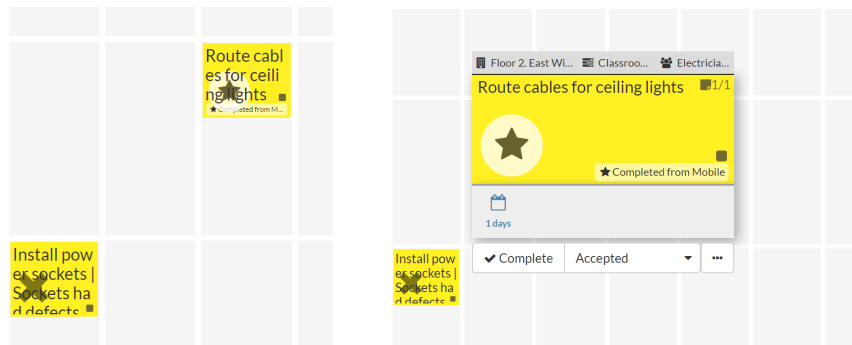


Figure 37: Left: Note marked with *completed* label as displayed in the board.
Right: Note marked with *completed*, expanded.

With this change active, notes could no longer be marked as closed from the mobile interface, reducing some of the potential for shortening meetings. Although making for a sub-optimal workflow in terms of efficiency, this should calm hesitant managers as they remain in control of which tasks get marked as closed, as this is still being done in meetings, while still receiving the benefits from users updating the status of work as it is performed. The hope was that this could also help in building trust if managers noticed that workers did report accurately, closing the note now serving as more of a final check. The opposite effect could also be experienced, as this feature makes it even more evident if a user misreports the status as it is no longer just a verbal exchange but logged in the task history.

Test results

In the end, a user's ability to add labels to notes depended on editing access and any tester would need to be given these permissions. Despite this, the Swedish site agreed to test this functionality, and the site manager reviewed it extremely positively. In the interviewees' opinion, this was the "correct" functionality, i.e. denoting what was completed to keep track for oneself while out on the site, then closing tasks together during meetings in front of the big screen. It was

stated that subcontractors shared this opinion and that all shared a perception of production meetings as an important activity for teams to synchronize and collectively identify problems as well as solving them together.

Although the notes now still had to be marked closed during the meeting, the label indicating what had been marked as completed was considered helpful and perceived to be speeding up the process of reviewing progress. However, it is important to consider that this certain project held daily production meetings, deviating from the norm compared to all other construction projects this study has been in contact with. This inherently results in meetings having fewer past notes to process (assumably 1/5th compared to if meetings were held weekly) during each meeting and that the need for updating the Yolean board before meetings is reduced as its always less than 24 hours to the next meeting (disregarding weekends). This implicates that the perceived benefits would, theoretically, be multiplied at sites with fewer production meetings per week.

Finally, an interesting reflection was made by the site manager during the feedback session, drawing on previous experience: "If I were a supervisor or subcontractor foreman, I would have just made my guys use my login and mark tasks as completed themselves when they're finished with them, instead of having to do it myself for them". Another interviewee with experience as a supervisor had similar thoughts when discussing who should be closing notes, wanting to make the trade workers do it themselves. This tendency implicates a possibility of this being the preferred workflow in projects with sufficient trust within crews. If the product does not support configuring user permissions in a way that makes this achievable, users may decide to break the system by sharing accounts, undermining traceability and making it hard to tailor the experience for different user groups.

5.3.3 Commenting

Motivation

As multiple interviewees claimed the ability for two way communication to be an important factor for use and commercial value, it was decided to try implementing a feature for this purpose to see what type of communication it would be used for. As it had also been identified that the list of pre-configured deviations was not considered adequate in describing issues with enough detail, a secondary purpose of the functionality could be to better support this use case. Similarly, the possibility to enter additional information could also work to relieve the issue with denoting partial completion of tasks.

Implementation

As the commenting feature for notes in Yolean is only available for question notes, a workaround had to be made as projects were already using job notes for their planning, and were unlikely to redo their planning in question notes for the sole purpose of testing this feature. Instead, comments were appended to the *summary* itself upon text entry. Unfortunately, no easy solution for including and/or displaying photos was found, hence the functionality could not be tested within the scope of this project.

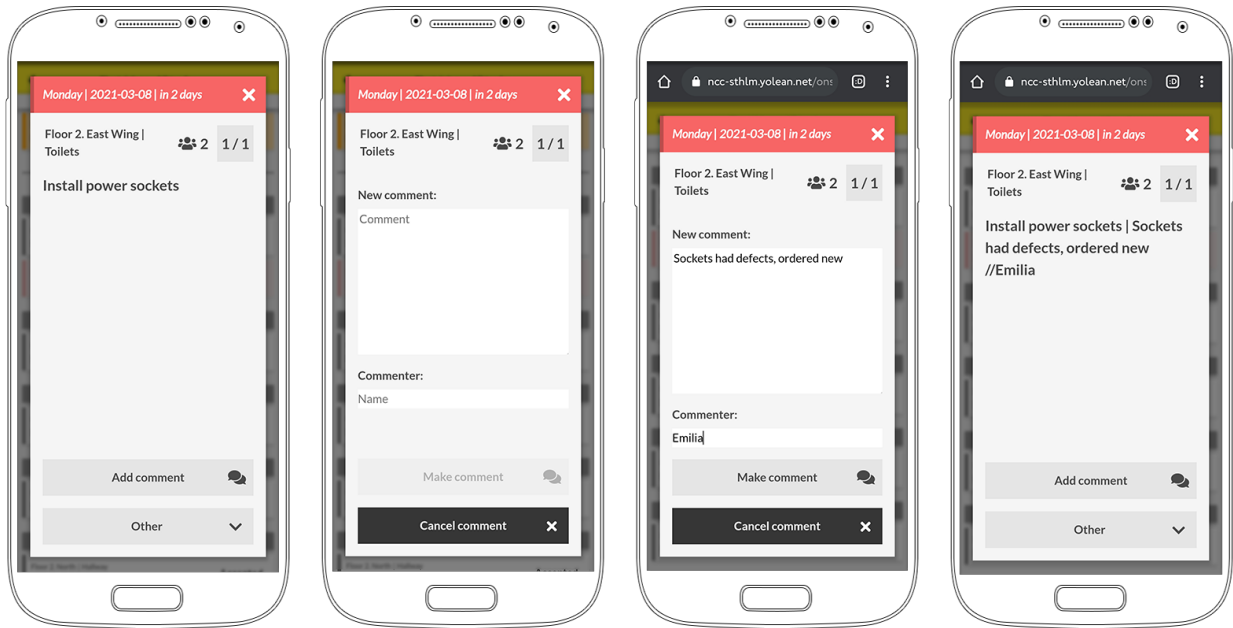


Figure 38: Showcasing the steps of adding a comment through the mobile interface in chronological order from left to right.

To make a comment on a note, a new button was added to *Note View* opening the commenting interface as the user would likely be making comments in combination with updating the state of a note (Fig. 38). As it was not possible to determine who made the comment due to multiple users using the same login credentials at the test site, a mandatory field for the name of the comment author was included to maintain traceability. Both text fields had to be filled in for the user to be able to make a comment, signified by an opacity fade on the confirmation button to indicate its otherwise disabled state.

Test results

Unfortunately, the functionality saw no use at the site during the testing period, albeit this being limited to a single week may have been part of the reason. The site manager still reviewed the feature and implementation positively, being content with how it was integrated into the interface, stating "it's a good addition for when its needed, and it doesn't hinder the regular use". The interviewee also reflected upon why it had not been used, concluding that they were in a less hectic stage of the project and that the daily production meetings sufficed for transferring information. If there had been more workers on site, or if they did not have meetings as regularly, they thought they would have used it to keep track of why an activity had been blocked, e.g. if they needed access to a tenants home but were not allowed to enter.

5.4 Summary and Implications

Summarizing the results of the study, the following sections discuss the implications of the findings for digital tools designed for collaboration in production control. Both in general terms as well as for Yolean specifically.

5.4.1 Needs and Requirements of Visual Production Control Software

The desired purpose of (mobile) applications for production control is seemingly to relay instructions, ease, as well as speed up, communication and assist documentation of tasks already agreed upon during production meetings. This so to overall ease the information flow within the organization, reduce time spent on unnecessary administration of data and assure that all documentation generated by the project is readily accessible. In all three cases, the information is commonly a mixture of graphic material and text, as visuals are required to make sense of the realities of construction projects, and serve to reduce the dependency on keeping information in memory. The knowledge transfer made possible through this information flow can then be performed in between meetings, allowing the time in common sessions to be spent more efficiently for its designated purpose, collaborative problem solving and commitment planning.

The content of the platform can be of use for all workers on the site, and functionality benefits from full inclusion, but as first level managers have the utmost responsibility for the execution of tasks, the decision of which trade workers are to be included should be left to these users. This decision can be adjusted gradually, and to support projects' differing needs and maturity in their integration of collaborative tools in their workflows, the platform must be configurable with variable access privileges for different user groups.

In the design of the tool, it was found that ease of interaction and visual clarity was of utmost priority and preferred by the potential users. The interface should be made to allow the inclusion of aforementioned user groups by presenting information so to be understood by all. The interface itself must also scale well with the size of projects so to not become a barrier for breaking down tasks in detail, and activity planners are already reluctant to perform detailed planning, but the literature encourages it.

Designs must also take into consideration how tasks are seemingly viewed as both activities and deliverables simultaneously by different users. Design tailored towards the general needs of development projects can not necessarily be expected to translate to those of construction projects and must either support the concepts simultaneously or clearly distinguish the difference between the two.

Considering also how many managers that are afraid to lose control and of missing workers' mistakes if they are not present, the design should make it easy to identify changes and for users to remain in control when additional groups are included in the usage. This also ensures that the responsible managers will feel assured that nothing can slip past them.

Finally, it is of note that the participants of this study have all shown an interests in digital-

izing their workflows but have seemingly not found tools sufficient for their needs. Existing workflows are often reminiscent of what is recommended by LPS (Section 2.2.4) and tools built to support this framework should be relatively easy to implement. Still, as users seem to lack knowledge of the theoretical backgrounds, training and guidance would be of great benefit to ensure that the implementation process goes smoothly and that the full potential of these tools is leveraged. However, the users are keen to keep their time spent on administrating these systems low, not wanting to use a multitude of tools nor anything they perceive as unreliable. If they do not find all the functionality they require, or perceive the interaction cost as too high, they are quick to return to the methods that they are already familiar with.

5.4.2 Recommendations For Yolean & continued development of the Mobile Interface

If future studies are to reuse the prototype developed in this study, or if Yolean wants to use it as basis for a commercial product, the following changes should be made based on the user testing:

- The bypass buttons at the top of each list view should be made larger and styled so to increase contrast compared to the rest of the elements in the list.
- The daily separators in *Notes List* should be modified into sticky headers so as to always remain in view while scrolling. See Bidelman (2017) for examples and implementation.
- The styling used for coding states throughout the interface could benefit greatly from further refinement and usability testing.
- The default root causes should be updated or modified so to better suit the context of production control.

Additionally, out of the functionality already available in Yolean's product, the following would be suitable to include in its mobile interface, especially in order to support power users and projects which leverage the advanced functionality available in the board view, e.g. using labels for sorting:

- Search functionality could be a necessity for usage in projects with high complexity or of larger scale. Some of the projects in Germany had 50+ subcontractors which greatly increased the interaction cost of scrolling in the list views.
- Due to the above mentioned reason, filtering by labels or predefined groups would be extremely useful for supervisors or block managers in larger projects. This also infers general methods for selecting multiple trades and/or locations.
- Adding question notes to the board so to quickly write down a note for QEHS-related issues or something which needs to be discussed during an upcoming meeting. E.g. waste disposal or similar topics which are not urgent enough to warrant a phone call.

- Comments and file attachments, as available in question notes, should be added to job notes as well to allow for attaching instructions or documentation. Performing associated actions should be possible through the mobile interface as well.
- Root cause analysis as an activity should probably not be performed in the field, nor by the worker reporting the status of the task. As the analysis requires training and dedicated time to perform, an option to mark with a deviation without root cause but instead accompanied with a comment documenting the issue would suffice, as well as lower the interaction cost of using the tool.
- Prerequisite work and its status should be accessible through the mobile interface so to avoid situations where a worker finds themselves unable to perform their scheduled work once they arrive at its location.
- Opt-in notifications was a feature interviewees were already using their email-clients or calendars for, some suggesting it could be integrated into the Yolean mobile interface. These should be opt-in only, serving as individual reminders for users who want to use them to get a heads up on certain activities if they know they will need time in advance for preparations.

Finally, the results of this study shows that there is a strong argument for that adding job notes should be possible from mobile devices, although this recommendation is made with some reservation. As previously discussed in this thesis, interactions with the mobile interface should not aim to replace meetings or the methodological process of commitment planning. However, conforming to the realities of construction projects, this is the seemingly best solution for ensuring that the Yolean board reflects the factual state and progression of the project.

To guarantee that the functionality complies with the requirements of hesitant site managers, afraid of misuse of the interface by subcontractors, and does not detract from the value of meetings nor causes unrepresentative statistics, the implementation must be carefully designed. Preferably, the coding of these added notes should signal that they are separate from planned job notes, by label or being a new note type altogether, and that they are not for planning activities but for the purpose of documentation. There is some support for this feature in the literature as well, where Ballard and Tommelein (2016) says that even though 100% PPC is the desired goal, standard deviation must be accounted for. Some weeks a team can perform better than planned, another week workers may be off sick or other unforeseen circumstances, such as the weather, causes disruptions and delays. One will never have a fully complete and accurate picture of the real world context when planning work, and this will inevitably always lead to some degree of variation in the outcome.

Ultimately, the main functionality needed in Yolean's product to unlock further potential would be further user profiling, primarily linking data such as trade to user accounts. This would allow for tailoring of the application so to deliver optimized experiences and would enable the nuanced permission system many of the interviewees have asked for. It would also enable seemingly low effort solutions for bridging the gap of trust necessary for the inclusion of sub-

contractors and trade workers. One suggestion for this could be that subcontractor foremen default to only being able to view job notes for their own trade, and if functionality for adding notes is implemented, only being able to add job notes for themselves. For trade workers, the already existing functionality of Yolean where individual users can be assigned to notes could be leveraged, creating a workflow where supervisors or foremen can assign their trade workers to tasks where the assignees can then only display these specific tasks. This would substantially lower interaction cost for these users by ensuring that they are only able to find what is relevant for them, mimicking the usage of screenshots found at the Swedish replumbing site, but also allowing end users to leverage the functionality available in the tool. By leaving the delegation of tasks to supervisors or foremen, who are ultimately responsible for the work of their crew, these still remain in control and can judge which workers to include in the usage of the tool and to what extent.

6

Discussion

The discussion is divided into two parts, the first relaying reflections on how methodology affected the outcome and was affected by external factors. In the second part, a discussion on how further work can elevate the developed prototype is presented.

6.1 Reflections on Methodology and Outcome

With the ongoing pandemic, certain aspects of the methodology used in this thesis proved difficult to carry out, and some considered methods were made impossible altogether. The interviews not being contextually held in person, coupled with fewer field study visits than intended, have possibly made for lower validity in the collected data. Ideally, field studies would have been performed repeatedly so to identify more closely how production control workflows may have differed on each site, and to elicit if behavior changed after the interviewees had gotten familiar with the authors. Discrepancies between in interviews stated and actual behaviors would likely have surfaced too, nuancing the answers to (RQ1), had it been possible to shadow key individuals over several days. Prolonged testing and closer observations of interactions with the prototype in context could have benefited the final version of the mobile interface as well with more integration into projects and insights for (RQ2).

For further insights into (RQ1), with potential carry over to (RQ2), workshops with site management from different companies and projects could have been useful to comprehend project differences further. It could also serve as a platform for knowledge exchange for participants, as well as for moderated co-design as the production management holds a great deal of experience. It should be noted though that the majority of participants in this study held civil engineering degrees, and at least half of them were relatively young. The study could have benefited from including managers with additional backgrounds, but the authors had to make due with the ones making themselves available to the thesis project.

Even without the pandemic, the distance and language barriers to test participants in Germany would have been problematic. Lead times were long for initiating and receiving feedback on tests, resulting in fewer prototype iterations than desired and a prolonged test period. Access was never granted for direct interaction via video or phone with the users, all feedback was fed through a middlehand. Controlling the user tests and gaining knowledge about the context in which they took place were therefore difficult. The survey eased in receiving direct feedback, but the intended response frequency was not met. It would have been beneficial to have survey respondents fill out the form several times in between releases of the different versions of the prototype, especially in the early releases where changes to the interface were greater.

The testing that was instead done in Sweden worked well, but due to time constraints on the

site's end it picked up too late to fully test and integrate the mobile interface into their workflow although it generated valuable feedback and discussion. It is likely that the outcome of the RtD-approach track would have been different had the testing been ruled by the Swedish project compared to it now having sprung out from several German projects. Should a similar project be done again, the authors recommend partnering with a contractor for prolonged and in-depth collaboration.

The end user of the mobile interface was deliberately not scoped for and left open in the thesis project. It could have proven useful to define a specific user for tailoring the experience of the mobile interface for one specific role persona and thus get further on developing the "right" interface for them. However, the RtD-approach intends to gain knowledge through design, and other aspects of findings may have been lost had the user group been narrowed down from the beginning.

Accessing the Yolean mobile interface was done by using the same URL as one would use to access the desktop version in one's browser. This was considered easy enough for users, but it is possible that people would have been more eager to test the prototype had it been available for download in an app store. Iterating on and updating the app would have been more tedious however.

On a final note, this project has struggled with the decision of designing to support a theoretically optimal workflow based on the recommendations of the literature, or to maintain a user centered approach, complying with the users' current needs. This reveals an interesting paradox where the tools to support the optimal workflow may not yet be available, making it hard to adopt these workflows, while the rarity of these workflows being practiced makes it hard to commercially motivate a product especially designed to support them. The lack of experienced practitioners also makes it hard to evaluate through user testing if designs do support the intended workflows. For testing to be performed, users would first have to be taught methods and methodologies such as location-based scheduling and LPS, making it hard to tell if a change in performance was caused by the tools or the new workflows. With that said, although this is outside of the scope of this study, combining the software as a service with education in the supported methodologies, such as LPS and lean construction, should make for a strong value proposition, if the possible results of using these methodologies as found by the literature can consistently be achieved among customers.

6.2 Reflections for Future Work

In the Yolean board, it is possible to add and view visualized relations between notes. It would have been interesting to test and see how useful this information would have been when accessed through the mobile interface in the field. For example whether it has implications for increasing the sense of commitment to tasks, sense of contribution to the team and project or if it could help to create a more trusting environment on construction sites. Implementation of displaying relations would need substantial design efforts in order to be presented clearly in the mobile interface, as well as extensive studies on which factors that contribute to the sense of commitment and trust.

The meeting mode, one of the experimental features (Section 5.3), was not tested as intended in a production control context as covered in section 5.3.1. With alterations to the Yolean board it could be implemented seamlessly and the mode deserves further investigation as praise was still given to it. This also further emphasizes that ease of use is the key to successful use of digital tools in production control. The potential of leveraging a smartphone based application similar to what was suggested for increased meeting efficiency remains, but relies on a stable implementation to be adopted by users.

This thesis has focused on production control only, but it may be important to explore and anchor research to project control to identify if there is more value to be gained by knowledge exchange of the different phases. Yolean is more widely used in project control in Sweden, and transferring technology appropriately could prove beneficial, as could training in management methodology for on site management, however more research is required,

7

Sustainability Aspects

The following section discusses the potential effects the results and envisioned end-product of this study may impose on sustainability aspects.

7.1 Social aspects

The fact that the prototype is developed for a smartphone device could mean that people with limited experience or interest in technology would have troubles accessing or operating it efficiently. Although further digitalization was advocated by the people in our study, it could cause age discrimination if new technology favors the young and require special competencies. To best avoid this, designs should consider accessibility aspects for all and attempt intuitiveness without only relying on established interface norms. Internal consistency, efficient navigation and consideration of resources are all strategies that can be leveraged to support learning. Further on the path of digitalization, with BIM gaining popularity on a global scale and possibly becoming mandated in Sweden as well (Section 2.2.5.1), the same issues will be faced by contractors lacking these technologies. This especially disadvantages smaller firms who may not have the resources to invest in the tools and competencies needed Dainty et al. (2017). As associated workflows, primarily ICE, calls for the inclusion of trade-specific contractors through the entire project, this has the potential to become an industry wide issue.

The same reasoning goes for management theory as well. If frameworks such as LPS and lean construction becomes common practice, this may greatly affect the career opportunities for personnel without higher education. Potentially, this would put an end to trade workers with a sense of leadership being able to advance to the supervisor role. The remedy for this issue would be further training through courses provided by the contractor or external sources. However, as this study has indicated that these are already lacking for current managers, it seems unlikely that contractors would investment in their trade workers' competencies regarding management theory.

Finally, if contractors would begin to mandate the usage of the end-product for reading tasks and documenting work in written format, this would disadvantage those not proficient in the language used at the site.

7.2 Environmental factors

The outcome of this project should have little to no impact on the environment. The move towards digitalization reduces consumption of material such as paper however the introduction of electronics in every part of our daily life has a negative impact in terms of material, resources and transport required to manufacture these products. With mobile devices becoming increas-

ingly powerful these can now perform tasks unimaginable a decade ago. Simultaneously, the ever increasing access to reliably fast mobile internet allows for cloud services such as Yolean to offload the need of processing power from the device running the application onto data centers.

Cloud computing is still an area where development is rapidly progressing and new performance and/or efficiency gains are frequently made. According to Koshy et al. (2012), offloading a demanding task from a mobile device to the cloud could reduce the time required to perform it by half while also consuming close to half as much electricity (including networking). With this knowledge we theorize that cloud computing services will in the future reduce the performance demand on mobile devices, allowing for more energy efficient hardware and reducing the size of battery needed. This means that cloud computing should offer potential for a reduced ecological footprint compared to running all software locally, provided that companies do not use unnecessary powerful devices and that the major cloud computing providers, such as Microsoft, Amazon, IBM and Google, take their responsibilities in moving the industry forward.

For example, Yolean is today powered by Google Cloud Services whose sustainability policies include matching all energy consumption with purchase of 100% renewable electricity and with the target achieving a decarbonized electricity supply by 2030 (Google LLC., n.d.). Furthermore, digitalization of planning and project management aims to provide performance improvements and cost savings. Efficient use of resources should generally also result in reduced emissions, e.g. by eliminating unnecessary transports or reducing material waste.

However, one potential consequence to be considered is the issue of contributing to the generation of electronics waste, often referred to as *e-waste*. As the study found it a potential issue that not all workers own, or want to use their private, smartphones, necessitating one for work would increase the sales of devices and it would be up to each subcontractor to make conscious choices in to which products they choose to purchase. Supervisors and foremen could most commonly be expected to already use a smartphone in their work but the same may not be true for trade workers, who make up the bulk of the potential user base. If these users are to be included in the usage of the platform, this dilemma might pose a notable issue.

7.3 Ethical considerations

The end-product may enable management to more closely monitor what activities are being performed, by whom, and when. Additionally, Yolean's customers have been asking for easy access to automatically generated KPI:s (Key Performance Index) for higher management so as to determine where to prioritize resources and easier identify projects that need active support to finish on time. This may raise concerns regarding surveillance and trust. Ultimately, the relationship between employees and management may be eroded if the data is used to control employee performance on an individual level. In turn, this could lead to disinclination to report, or cause disruptions in the intended use of the end-product. Although lean theory advocates measurability, its reasoning for this is to enable root cause analysis and design of countermeasures. If the information is simply served to users without intent of performing these activities, or who does not share the philosophy of striving for team performance, there are considerable

risks for misinterpretation of causes and that feedback is not presented constructively.

The lines between quality control, performance monitoring and outright surveillance can be hard to define. On one side, ensuring that the client gets the results that they have paid for should be good business practice but the same data could also be used for more nefarious surveillance purposes. Although workers who routinely underperform due to lack of competence, negligence or laziness should be protected from consequences, the same functionality could enable practices such as withholding a raise in salary or threatening to fire someone over not performing as well as their colleagues. Some may believe that creating competition between workers can be positive for performance but aggressive surveillance resulting in always being on alert will likely cause stress and over time reduce individual performance. We do not believe management by fear to ever be a sustainable business practice, but in some cases it may be up to the design to prevent this behaviour to be possible in the first place.

When it comes to the study itself, we have had to ensure that methods of observation and data collection did not invade the privacy of the participants or other individuals without their consent. We have also ensured that survey responses or information from informal interviews that may reflect badly on individuals are not disclosed to their managers or can be linked to them individually.

8

Conclusion

Sites studied in Sweden used a variety of management tools, ranging from analog to digital, some with an accompanying smartphone application. Results indicate that knowledge of modern, scientifically established, methods for efficient production control seems to be somewhat lacking at construction sites. An obstacle found was that some site management were reluctant towards detailed planning, claiming it to be too time consuming without generating value, viewing it as pure waste. Literature does not agree, and presumably this view is caused by the aforementioned knowledge gap. Another obstacle faced is issues with trade workers misreporting progress of work, both intentional and unintentional, causing intra-organizational mistrust. The lack of trust becomes an obstacle in itself, complicating the use of collaborative tools as management limits access to functionality, preventing them from being used to their full potential.

The prototype developed in this thesis supports the main use cases in production control and users are able to view activities, direct their staff and update the status of notes in the board. Filtering and color codes increases the clarity of the listed notes and the mobile interface was found to add value for Yolean's product in terms of being portable and accessible when it needs to be.

Yolean users were positive towards the mobile view and all site personnel, from site manager to skilled workers, had a legitimate interest in accessing their job notes anywhere from their phones. The users accessing the production plan through a mobile interface should at the least be those present at the production control meetings, i.e. site manager, supervisors and subcontractor foremen/representatives, until sites have the trust and routines in place to include all workers.

For widespread adoption in production control, users would require two-way communication with text and pictures connected to their notes. Additionally, detailed configuration settings are needed so to adapt to projects of different character. Beyond that, linking drawings and other documents to tasks would further aid collaborative workflows and would give Yolean a competitive position in the construction industry.

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