35th Annual INCOSE international symposium
hybrid event
Ottawa, Canada
July 26 - 31, 2025

Integrating Concept of Operations in Prefabrication Processes for Effective Construction Projects: A Case Study on Plumbing Systems

Karl Martins Obote
University of South-Eastern Norway
Kongsberg, Norway
Karlobote@gmail.com

Gerrit Muller
University of South-Eastern Norway
Kongsberg, Norway
Gerrit.Muller@gmail.com

Satyanarayana Kokkula
University of South-Eastern Norway
Kongsberg, Norway
Satyanarayana.Kokkula@usn.no

Tobias Fredrik Lynghaug
Bravida A/S
Oslo, Norway
Tobias.Lynghaug@bravida.no

Abstract. This study examines how a Concept of Operations model integrated into a prefabrication process addresses the challenges of project cost and delivery time in plumbing operations from a technical contractor's perspective. First, we analyzed the process flow to identify the pain points faced in the plumbing process and developed an As-Is Concept of operation model. We identified the factors affecting prefabrication of cost, labor, time, and logistics as provided by state-of-the-art. Second, we mapped out the workflow and proposed an improved model that addresses the challenges, with findings showing improvements in both time and cost savings for projects. Finally, we supported the findings with a cost model and evaluated the proposed Concept of the operations model with industry experts. These experts foresee the proposed model as a good recommendation for rethinking the process and setting up a streamlined prefabrication line. With the proposed model, we made an estimation for a selected building site, which revealed time saving of 1911 hours translating to 573 KNOK. To verify our results, we suggest additional testing before proceeding with full-scale implementation on a construction project.

Keywords. Prefabrication, Concept of Operations, Construction, Plumbing.

Introduction

Norway is a Scandinavian country with an estimated population of 5.4 million people. The population growth rate shows an increase of over one percent in 2023 since 2015, indicating a consistent growth rate (Statistics Norway, 2024). This population increase necessitates the Norwegian government to work with the construction industry stakeholders to develop infrastructure and buildings to accommodate the population increase. The Norwegian construction industry is one of the largest sectors in Norway. It has an annual revenue of 838 Billion Norwegian Kroner (NOK) in 2022, representing a compound annual growth rate of 4 percent between 2017 and 2022 (Market research, 2024). The industry is undergoing growth and expansion with technologies focusing on digitalization, innovation, and sustainability in project delivery. The projects emphasize cost-effectiveness, efficiency, and environmental considerations (Lynghaug et al., 2021).

Mechanical, electrical, and plumbing (MEP) are the technical aspects of construction, including water supply, firefighting sprinklers, drainage systems, heating, ventilation, air cooling, and electrical power systems (Dallasega et al., 2021). The value generation of plumbing, heating equipment, and hardware in Norway has increased by 37% from 2009 to 2019. Plumbing is essential role in the development of Norway's construction and infrastructure (statista, 2023). Plumbing systems are subject to stringent standards and regulations in Norway to ensure efficiency, safety, and sustainability. The building and infrastructure stakeholders are contractors, local authorities, public road administration, Norwegians, and private organizations (Ministry of Trade, 2001).

Current approach to construction projects: The current industry practice is the traditional on-site assembly of building materials, also known as the conventional or site-built method. Raw materials are acquired according to the bill of quantities and delivered to the construction site. The technical contractor fits and installs the materials according to the building design (Kamali et al., 2019). This method requires a significant amount of labor, time, and resources. The laborers work longer on onsite to deliver within the project's timeframes. This increases labor costs and can affect project timelines (Yan et al., 2024). The weather affects the onsite construction project delivery plan, leading to delayed delivery time (Lynghaug et al., 2021). The industry accounts for a considerable share of total energy and materials consumed in Norway, and construction has a large share of the overall waste generated in the country (Ministry of Trade, 2001). Norwegian industry productivity increased from 2008 to 2018 by 30%. However, the construction industry productivity decreased by 10% (Lynghaug et al., 2021).

Industrial Context and Needs: Bravida AS is a leading Nordic technical construction company offering solutions throughout a building's technical lifecycle, including engineering, design, installations, and maintenance services (*The Bravida Way*, 2023). Bravida serves both small- and large-scale projects, installing plumbing and heating systems in companies and households. They employ innovative installation systems for plumbing and heating systems in complex facilities such as hospitals (*Heating and Plumbing Servicing*, 2023).

Bravida categorizes its operations into four primary processes: tendering, preparation, assembly, and installation. Figure 1 illustrates the tendering process and interaction between the stakeholders. The stakeholders include the customer, main contractor, and technical contractor. The boxes on the left side of the diagram represent stakeholders participating in the plumbing process and engaging in activities within their respective streams. Figure 2 illustrates the system of interest for this study, showing the preparation, assembly, and installation processes. Stakeholders in Figure 2 include the head plumber, project manager, consulting firm, and technical disciplines.

The As-Is Concept of Operations (CONOPS) process at Bravida AS is agile and involves continuous improvements through feedback, negotiations, and adjustments. The Project manager for Bravida AS and the main contractor apply the Deming cycle of the plan—do—check—act concept in the process to have iterations and feedback for continuous improvement (learnorg, 2024).

Problem: Bravida AS faces multifaceted challenges in project planning and execution phases of plumbing operations. The challenges include project delays, cost overruns, and logistics management. There is an opportunity to enhance the construction process to improve time and usage of financial resources. Addressing these areas will support onsite installations and contribute to meeting project delivery expectations within the anticipated cost and schedule.

Goal: Bravida seeks to manage stakeholder concerns related to project delays, logistics management, cost overruns, and physical waste management. The study aims to investigate a method to streamline processes, reduce project costs, and shorten delivery times in plumbing operations.

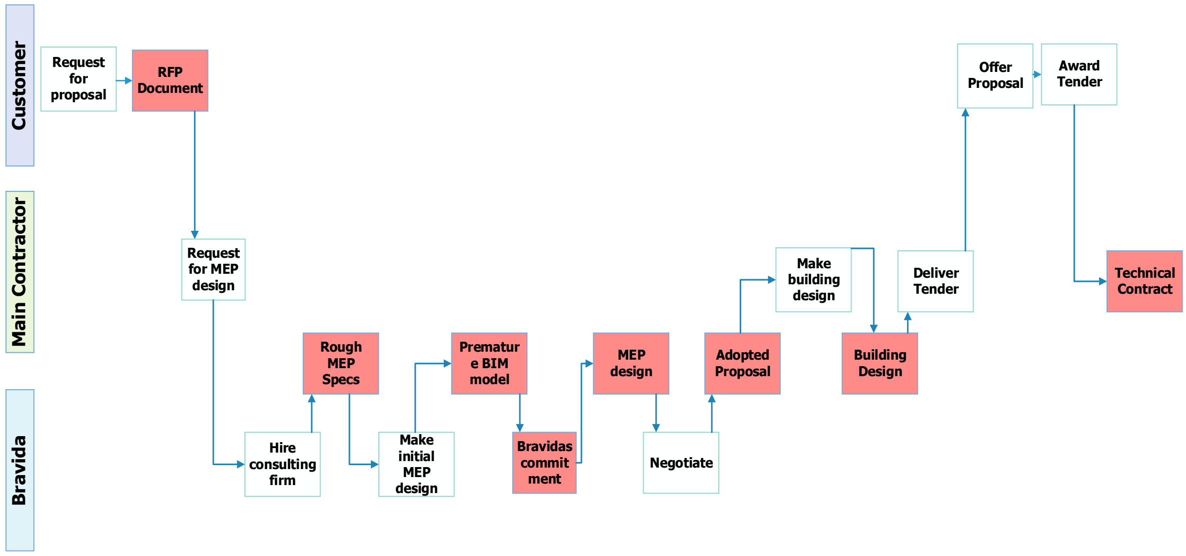


Figure 1. Tendering Process at main contractor and Bravida AS

Solution. The proposed solution integrates a CONOPS model in a prefabrication process to address the challenges. The objective of the proposed solution is to meet Bravida's needs in reducing project costs and delivery times for plumbing operations. Additionally, a cost model is important to support the implementation of CONOPS.

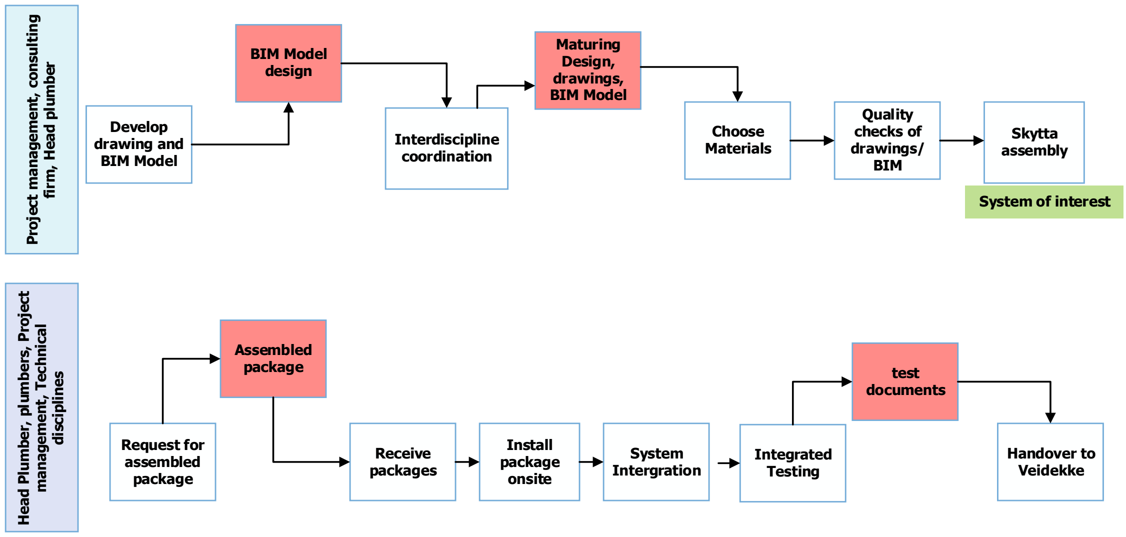


Figure 2. The preparation and installation process at Bravida AS

Prefabrication: In the construction industry, prefabrication or modular assembly involves the offsite production and preassembly of building components, which are then transported to the construction site for installation. The components are assembled offsite from separate self-sustained volumetric modules or panels (Gunawardena & Mendis, 2022) Prefabricated homes are in high demand as they are less expensive and take less time to construct than onsite-built homes (mordorintelligence, 2023).

CONOPS: CONOPS is a Systems Engineering tool that graphically represents the stakeholders' interests, and it has become a platform for validating technical requirements and system architecture (Verma, 2014). CONOPS assists in setting up and understanding a proper prefabrication process and standards. It shows the operations with specifications to address stakeholders' needs and achieve company objectives. The development of the CONOPS model occurs during the project development lifecycle's concept stage [ISO/IEC, 2008]. CONOPS helps in the identification of pain points and how to address them using a systematic approach (Mostashari et al., 2012).

Standards: ISO/IEC/IEEE 29148:2011 is the current standard for developing a Concept of operation (IEEE, 1998). The standard outlines the scope, referenced documents, As-Is situation, nature of changes, proposed system, operational scenarios, and summary of impacts (Mostashari et al., 2012).

Rationale: The CONOPS model maps the As-Is state to identify pain points and stakeholders' needs and create a To-Be model prefabrication solution that addresses project delivery needs. These needs include managing cost overruns, delivery time, labor hours, logistics, and physical waste to streamline the plumbing process in the construction industry.

Research question: How to develop a CONOPS model to help achieve an effective prefabrication process for plumbing systems in construction projects?

Sub questions:
RQ1: How to develop a CONOPS model to identify pain points in the As-Is state and propose a To-Be plumbing solution state?
RQ2: How can prefabrication help reduce project costs regarding physical waste, logistics, and labor?
RQ3: How can prefabrication help reduce project delivery times at the construction site?

Exploring RQ1 requires the CONOPS models to identify the pain points faced by the technical contractor and suggest possible solutions. Answering RQ2 shows whether prefabrication contributes to reducing the elements affecting project costs. Answering RQ3 illuminates whether prefabrication can reduce project delivery times. The answers will ascertain whether the CONOPS model integrated into the prefabrication process in a plumbing process can address technical contractors' challenges.

Case site: In the selected project, the stakeholders include a customer, a general contractor, and Bravida AS as the technical MEP sub-contractor. The construction site is located at Ulvenveien 90 Oslo, has 5 floors, (see Figure 3), with an offsite warehouse situated at Industriveien, Oslo. Our research concentrated on the Sprinkler system (part of plumbing systems) on the building's fifth floor. We named the warehouse as 'Skytta' and focused on the plumbing processes.

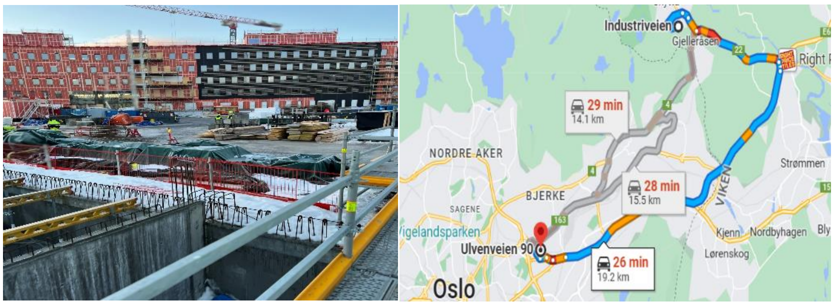


Figure 3. Bravida Ulvenveien project, and a map showing the distance between the office, Skytta, and the site.

State of the Art

Construction: According to (Kamali et al., 2019), there is a significant demand to increase infrastructure and building globally due to population increase. The construction industry employs one hundred and ten million people and contributes thirteen percent of the global economy globally. However, the industry faces growing economic, social, and environmental challenges as it consumes half the world's resources. Xing (Xing et al., 2021) share that construction companies face project delays, safety, quality flaws, and cost overrun risks in construction projects.

Plumbing: Plumbing is a system used to transport liquids, gases, heat, and waste from one building location to another. Plumbing is standard in commercial and domestic buildings. Plumbing components include valves, pipes, connectors, and fittings (Li et al., 2017). A MEP contractor is usually in charge of a subsystem, such as a plumbing subsystem. The MEP contractor is responsible for procuring the subsystem's required raw materials. Figure 4 illustrates a plumbing construction's traditional supply chain system (Li et al., 2017).

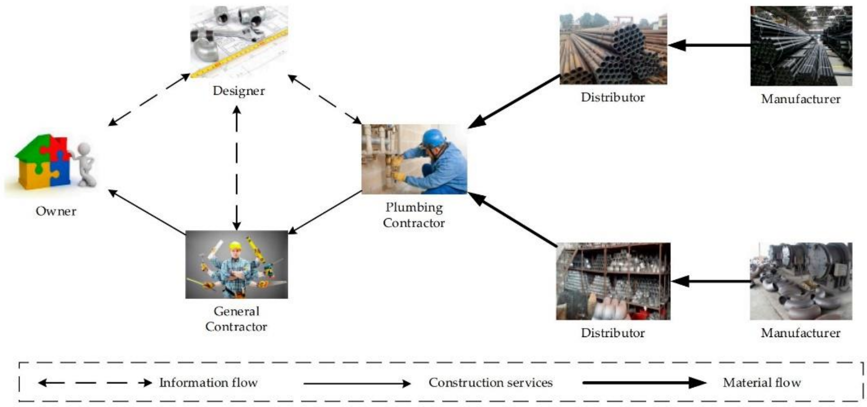


Figure 4. The supply chain of a traditional plumbing system (Li et al., 2017)

Prefabrication: Kamali (Kamali et al., 2019) dives into prefabrication using Life Cycle Assessment to differentiate between traditional and modular construction. The modules are assembled off-site in modular design, transported to the site, and installed on permanent foundations. Conventional construction phases include design, material production, and use. However, in prefabrication, we have building design, assembly, modularization, and transportation of components. According to (Tavares et al., 2021), Time consideration for construction projects is key for successful prefabrication. This time includes prefabrication, onsite assembly, operations, and end-of-life disassembly. Figure 5 shows inflow and outflow in the construction industry to contextualize conventional construction and prefabrication.

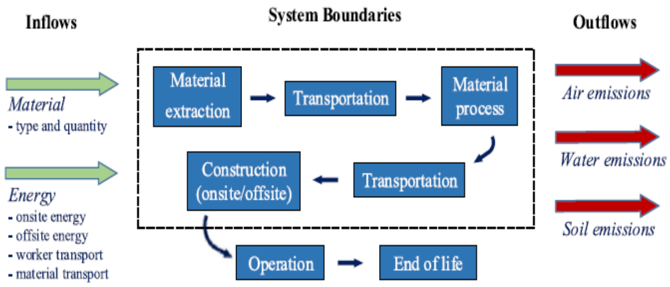


Figure 5. System boundaries cradle to gate (Kamali et al., 2019)

Concept of Operations: Mostashari (Mostashari et al., 2012) defines CONOPS as a document that displays a user's intended usage or characteristics of a system. Its purpose is to provide a basis for communicating its qualitative and quantitative aspects and discussing the system's characteristics with stakeholders. The articles emphasize that CONOPS minimizes materials waste by reducing excess inventory and managing material usage. The document ensures a well-defined standard and quality to minimize defects and rework by ensuring the components are of superior quality. The CONOPS model will help manage and reduce time wastage, as it will comprehensively overview the critical milestones and project timeline. CONOPS highlights three key areas: stakeholder involvement, shared mental models, and visualization, offering ways to enhance the development process as shown in Figure 6. It helps identify pain points and provides systematic approaches to address them. (Mostashari et al., 2012).

According to SEBoK (SEBok, 2024) CONOPS covers a connected operation series carried out in succession or simultaneously. CONOPS gives a picture outlook of the operation in the organization. It proves the basis for bounding the system capabilities, interfaces, operating space, and environment. Korfiatis (Korfiatis et al., 2012) recommends developing a graphical model-based CONOPS to improve

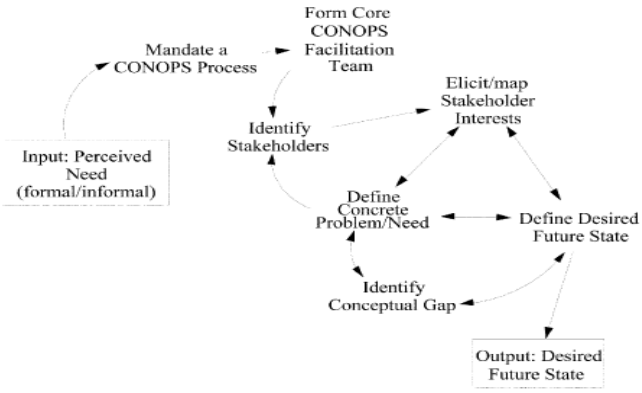


Figure 6. CONOPS Conceptual model (Mostashari et al., 2012)

the existing techniques and convey stakeholders' requirements. The CONOPS represents an advanced method of establishing an integrated approach to Systems Engineering. The graphical CONOPS model-based approach helps represent the construction industry's prefabrication needs. Figure 6 shows CONOPS steps in the conceptual phase.

Aspects factored in a prefabrication process: According to (Lee et al., 2021) Project costs, logistics, time, and labor are essential to achieve prefabrication objectives. The objectives include improved building quality, reduced project delivery duration, and cost reduction. Operation logistics during prefabrication focuses on positioning resources at the right place, time, cost, and required quality. Shih (Shih et al., 2005) focuses on prefabricated components and module storage. The prefabricated modules are stored in the warehouse units and transported to the construction site when required, depending on the construction plan. A unique mark is placed on each module to be assembled, making storage and installation easy. Similar marked modules are stored together. Jannasch (Jannasch, 2012) shares the importance of considering labor, as each sub-trade executes specific operations. This labor is compared to earlier skilled laborers who required less training than craft people with hand tools. According to (Shehata & El-Gohary, 2011), the construction industry is suffering from a decline in productivity compared to other industries. Equation (1) illustrates the productivity calculation as the unit produced per person hour.

$$Productivity = \frac{output}{\text{labor+equipment+materials}} \quad (1)$$

According to (Seaker & Lee, 2006), offsite activities consisting of material movement affect the degree of economic feasibility in prefabrication. The cost increases due to the distance, number, and configuration of supplies and shipments to a project of modest size. The relationship between cost and time is among the variables identified and analyzed. According to (Yi et al., 2019), the amount of physical waste in prefabrication is less than two percent. According to (Mao et al., 2016), stakeholders such as the customer and design firm cannot personalize prefabrication features due to an increase in components' costs. The capital expenditure (CaPex) of setting up a prefabrication site to prefabricate components is cost intensive.

Research Methodology

This research includes a case study and exploratory approach combined with observations, previous documentation, and interviews. The case study method is important in elaborating on contemporary circumstances, such as factors affecting labor shortage (Yin, 2017, s. 9). This research is limited to the context of plumbing systems within the construction industry to avoid the common pitfall of trying to answer broad research questions in case study research (Lynghaug et al., 2021). The research used an exploratory approach due to the limited information available to understand the case. This approach will enhance our understanding and facilitate the explanation of how or why a phenomenon occur, enabling us to make future predictions (George, 2021).

Data Collection and Analysis

This study is structured into four distinct phases, each serving an important role in our research journey. Figure 7 provides a visual representation of this progression: understand, investigate, propose, and evaluate. This systematic approach allowed us to dive into the system engineering body of knowledge, primarily through a comprehensive literature review in the construction domain. Additionally, we conducted interviews with stakeholders at three key locations: the construction site, Bravida offices, and Skytta offsite warehouse.

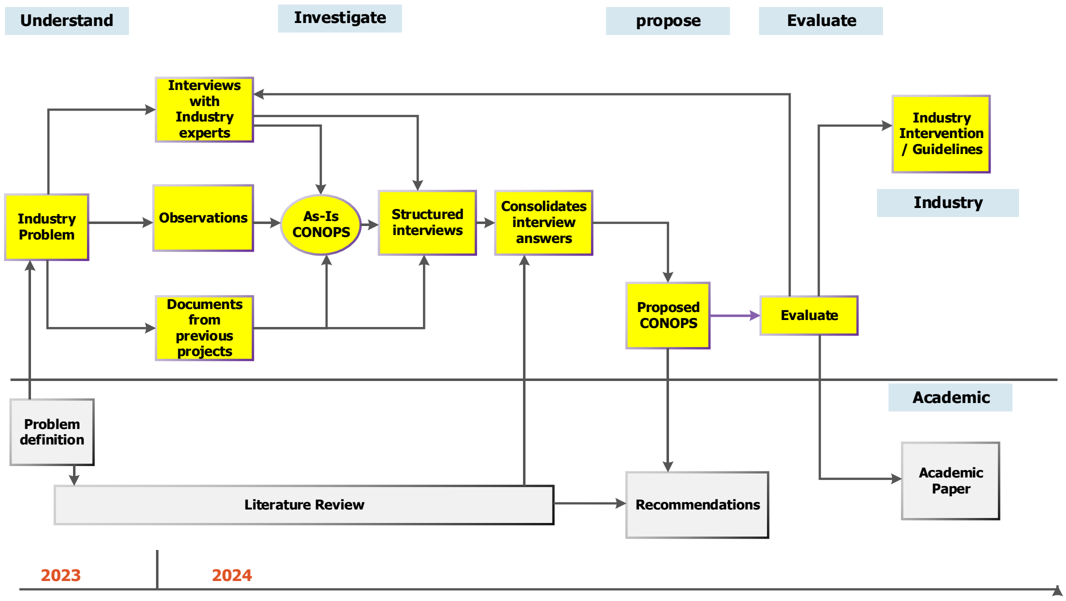


Figure 7. High-level overview Research Design

Understand: We first had to understand the industry problem. This led us to engage in a formal conversation with Bravida's Technical Project Manager to collect information and gain an understanding of Bravida's challenges. The project manager introduced Bravida AS's vision of prefabrication and company culture. Next, he took us around the three sites to meet and interact with key stakeholders.

Investigate: We conducted a literature review to understand the problem within the academic domain and used data to understand the industry domain. During operations, the lead researcher visited the Skytta site to observe how the plumbers assembled the plumbing packages offsite. Followed by visiting the construction site at Ulvenveien, Oslo during the installation of packages on the fifth floor. We reviewed available documents from previous projects and conducted semi-structured interviews with Bravida's key employees. The employees include the branch manager, project manager, skilled plumbers, and head plumber. The purpose is to determine Bravida's current state and develop an As-Is CONOPS model. The formulated structured interview questions determine the following. First, we identified the pain points Bravida faces during project execution. Second, we determined the stakeholders' knowledge and understanding of prefabrication. We conducted interviews at the assembly of sprinkler pipe packages that were in progress to understand the workflow and measure the time each step takes. We analyzed notes and feedback from the observations and interviews.

Propose: The lead researcher created a To-Be CONOPS model from the analysis, addressing the pain points faced at the Skytta assembly. The Proposed model includes the stakeholders, their needs, and their solutions. We aimed to have a standardized workflow process to increase efficiency and quality in the long term. A cost model supports the proposal to understand the feasibility of the model.

Evaluate: We evaluated the proposed CONOPS model with the industry experts in a meeting. We used structured questions to guide the evaluation meeting. Bravida's key employees, including the project manager and Branch manager, evaluated the proposed model as representatives of the industry domain. The academic supervisors also evaluated the proposed model. We adjusted the final model based on the feedback from the industry experts and academic supervisors.

Limitations: This study relied on assumptions about project cost figures due to a lack of sufficient data and documentation from previous projects. To address this limitation, we gathered data from similar companies in the same industry domain.

Case site: Skytta Offsite Assembly Warehouse

Bravida AS faces challenges in project delivery time and cost. Customers who are key stakeholders of Bravida require projects with a 20 % cost reduction. Bravida AS created Skytta's offsite assembly to improve project delivery times. Skytta warehouse site enabled the relocation of plumbing materials assembly operations from onsite. However, Skytta needs to deliver on its intended objective of reducing high costs and delivery times. We used the graphical CONOPS model to map the process flow at Skytta. We conducted interviews and observations and collected data for mapping. We started by mapping out the offsite assembly process at Skytta using the high-level CONOPS model. Figure 8 shows three general stakeholders: the head office, skilled plumbers, and delivery driver.

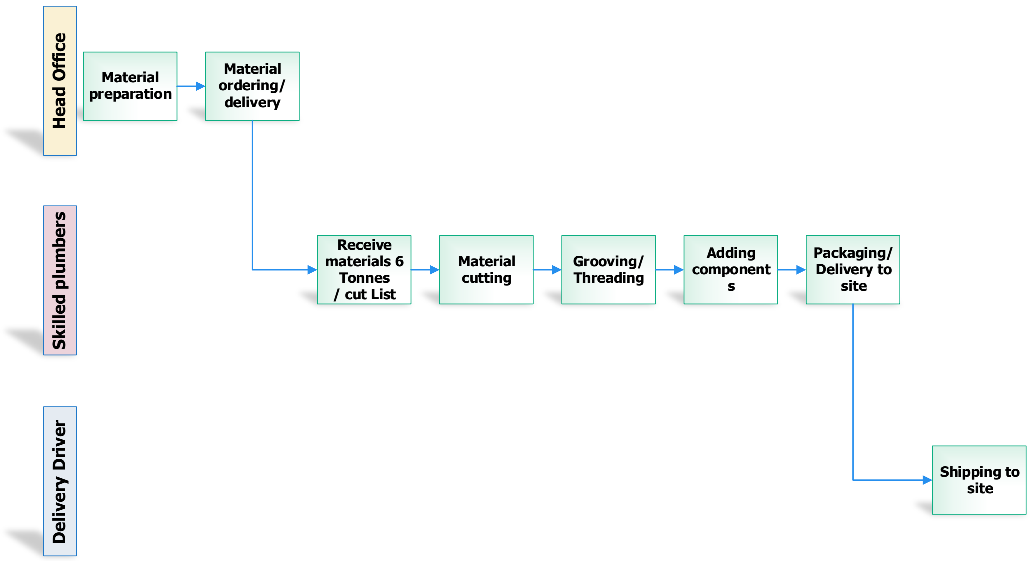


Figure 8. High level Skytta offsite process

Research findings

Figure 9 illustrates the As-Is scenario of the system of interest, where we look at the tasks conducted by each skilled plumber, equipment, pain points, and materials. Figure 9 presents the assembly workflow of a Sprinkler pipe system at the Skytta assembly site. The process flow includes three skilled plumbers, while mapping out pain points affecting the process delivery times. Figure 9 shows the pain points collectively account for 50 minutes, which directly impacts on the overall delivery time per pipe. The 50 minutes does not consider changing the saw and feedback loop time. It takes 10 working days to assemble 6 tons of pipe packages for a Sprinkler system per floor. Quality checks occur between specific steps in the process, such as pipe separation and component addition.

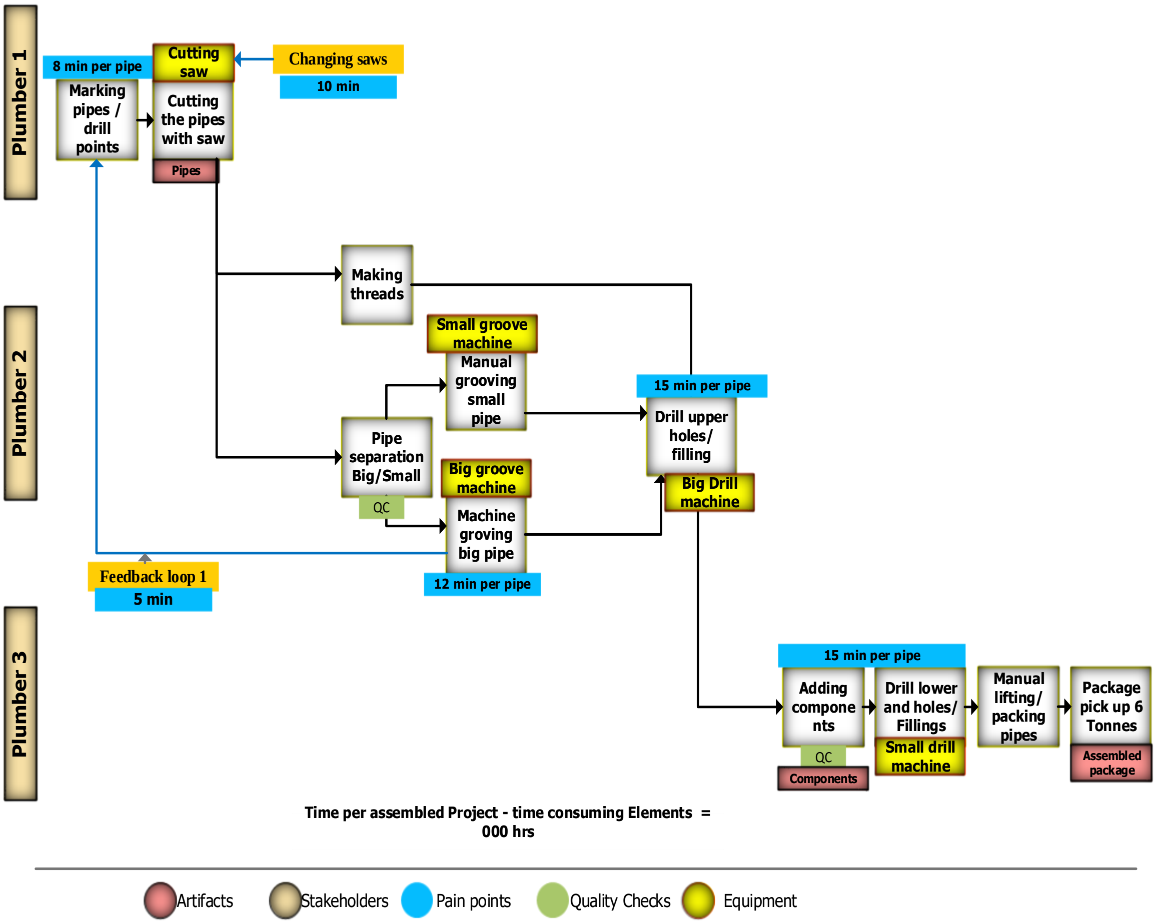
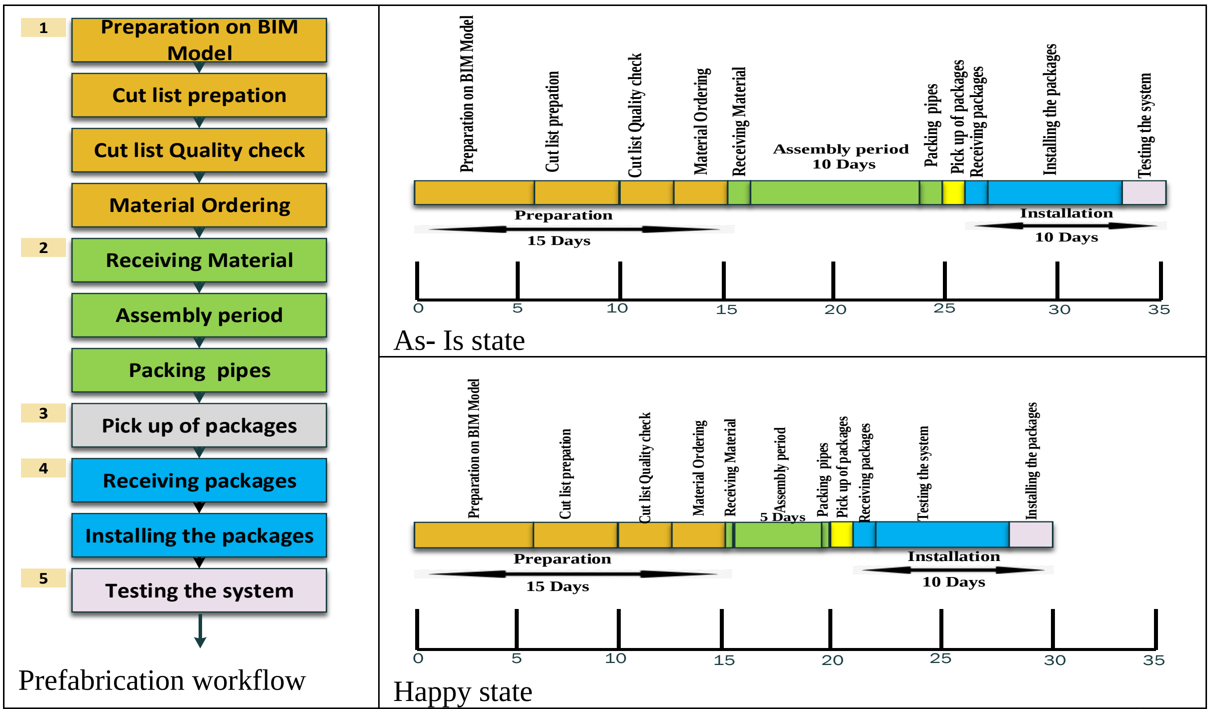


Figure 9: As-Is model of the offsite assembly Process at Skytta.

Bravida AS designed the Skytta assembly warehouse to save time and cost taken in projects. However, the CONOPS mapping shows a difference between the current As-Is and the desired Happy State. The happy state is the state Bravida envisioned for Skytta. Figure 10 illustrates five primary steps in the assembly process and the time required for each step. The external consultant designs and shares the Building Information Model (BIM) plumbing architecture design. Bravida's BIM model plumber converts the BIM model design to a cut list. The head plumber confirms the cut list and approves if it is accurate. The BIM model plumber orders raw materials for Skytta and sends the approved cultist for assembly. The first step in the workflow requires fifteen working days to complete. This extended period is due to the time it takes to translate the plumbing system measurements into a cut list and quality check. The color in the workflow corresponds with the colors in the CONOPS model state. Figure 10 shows the current As-Is state uses 35 days to prepare, assemble, and install pipes. However, the envisioned happy state was to use 30 days. We estimated the time and cost lost between the Happy and current states.

The difference between Happy and As-Is states is 5 days for the entire process. A total of 93 hours are lost in the assembly process of 159 pipes, which translates to a lost cost of 69.8 KNOK. The entire office building at Ulvenveien consisting of 5 floors requires 13 consignments of 159 pipes, leading to a total cost loss of 363 KNOK.



Woker cost per day	
Hours per day	7.5
Wokers per day	2.5
Cost per worker (NOK)	300
Total	**5625**

Happy State Assembly time 5th floor	
Hours per day	7.5
Workers per day	2.5
Assembly time (Days)	5
Total time per 6 tons	**93.75**

As-IS Assembly time 5th floor	
Hours per day	7.5
Workers per day	2.5
Assembly time (Days)	10
Total time per 6 tons	**187.5**

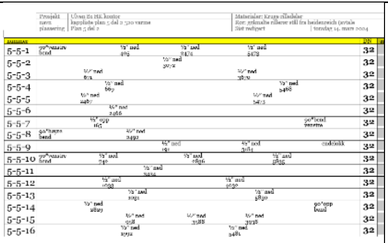
As- Is time = (187.5 /159) * 60 = 71 min per pipe
Happy state = (93.75/159*60) = 35 min per pipe
Lost time = 71-35 = 35
=(35*159/60) = 93 hrs
Lost cost = 93*300 = 69.8 KNOK

Item	Meters
Heating	2430
Sprinklers	7610
Cooling	2694
	12734

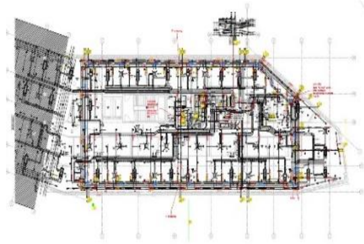
6 tones in meters	159*6= 954
	12734 /954=13
As/Is	187.5*300= 56250
NOK	56250*13=731250

Figure 10: Work overtime calculation As-Is model for Skytta.

Figure 11 shows the artefacts and cut list for the fifth floor of the office building site at Ulvenveien Oslo. Picture (a) shows the cut list made from the design BIM Model 1 and 2. Pictures (b) and (c) are the two phases of the fifth-floor design in the BIM Model, showing the layout of the sprinkler systems with measurements. A contracted consulting company models the BIM design, and a skilled plumber with BIM model expertise translates it into a cut list. Using the 6-meter pipe guidance from the BIM model, the plumber creates the cut list, which the head plumber checks, revises, and sends to Skytta. Picture (d) shows the cut list delivered to Skytta for assembly guidance and quality check by skilled plumber 1. Picture (e) shows the 6 tons of raw material pipes that were received, which are 6.1 meters long. Picture (f) shows packed pipes with added components by skilled plumber 3. Picture (g) shows the pipes skilled plumber 1 numbered to assist in identification and installation at the site. Pictures (h) and (i) show the assembled pipes being packed and delivered to the construction site. Picture (j) shows the pipes fitted together according to the marked numbers per the cut list. Picture (k) shows the installed sprinkler pipes for the fifth floor at the construction site, which are ready for testing.

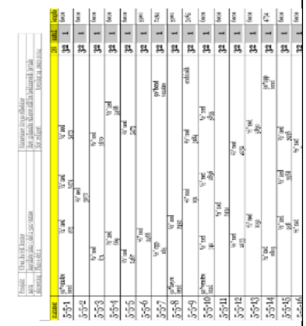


a). Cut list made from BIM model 1&2

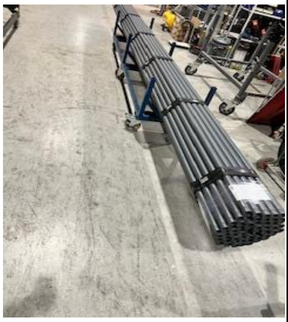


b). BIM Model design 1

c). BIM Model design 2



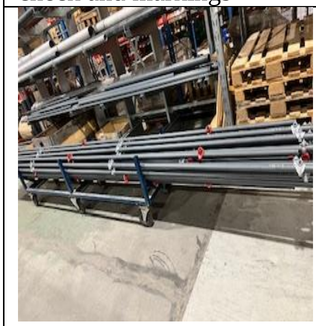
d). Cut list for quality check and markings



e). Raw Materials pipes 6 tones

f). Components added to pipes

g). Numbered pipes as per BIM model



h). Packed and ready for delivery

i). Packages on site

j). Fitting according to numbering

k). Installed pipes

Figure 11: Artefacts and packages produced for and at Skytta.

Challenges affecting the assembly process at Skytta.

Plumber 1 manages the marking and cutting of the 6 tons of raw pipes, which takes 8 to 20 minutes per pipe due to an old and slow cutting saw, pipe markings, and blade change. The blade changes depending on the type of pipe in assembly for instance, cutting stainless steel requires a different blade from cutting steel pipes. Second, incorrect cut sizes from the cut list sent from the head office to Skytta caused delays. Addressing these errors takes over 5 minutes, affecting delivery times. Plumber 2 manages two steps in the assembly process, grooving and hole drilling, which is demanding compared to the other plumbers, thus slowing down the productivity of Plumber 3. Plumber 2 makes grooves that take 12 to 15 minutes per pipe due to the division of the process for small and big pipes. The process has a manual handheld groove machine for small pipes and a slow groove machine for big pipes. Drilling and filing holes take 10 to 15 minutes, as drilling occurs on the top part of the pipe.

Plumber 3 adds components, drills holes on the sides of the pipe, and smoothens the edges of the pipe. This process takes 10 to 15 minutes, as Plumber 2 does not drill the sides indicated on the cut list. The manual lifting of the assembled pipes and placing them in the pipe racks can be strenuous and lead to injuries, slowing down the process. Other challenges include limited space for effective assembly, leading to waiting periods for material delivery. Skytta currently utilizes only 30% of the rented workspace due to equipment storage that is not in use. The need for sufficient storage for completed packages further disrupts workflow. This disruption means that only one package of 6 tons of raw material can be assembled at a time, thus affecting logistics costs and project delivery times. Physical material waste is unaccounted for and written off per project.

Proposed To-Be CONOPS scenario.

Exploring a graphical CONOPS model in prefabrication within the Skytta assembly site offers avenues for addressing the challenges faced by Bravida AS. We created a To-Be model using the As-Is model as guidance to address the pain points at Skytta. The proposed To-Be CONOPS model tackles the pain points experienced by Bravida AS at its offsite Skytta assembly warehouse. The To-Be model illustrated in Figure 12 efficiently allocates work among the three skilled plumbers. This allocation aims to prevent process delays and reduce waiting times. We divided the process into two parts: one for assembling Polyvinyl chloride (PVC) materials and the other for assembling steel and stainless-steel materials. Quality checks conducted at the beginning and end of the process ensure that the assembly process maintains its integrity. The quality checks include the accuracy of information from the cut list, components' availability, and materials' quality.

Plumber 1 is responsible for marking and cutting the pipes within 2 minutes and 30 seconds due to the specialized equipment used. He makes grooves in steel pipes, threads for both PVC and steel pipes, and sends the material through the conveyor belt to Plumber 2. Plumber 2 prepares PVC and stainless- steel components for welding and connects short pipes. He drills holes and files the edges on PVC pipes to ensure quality holes for attaching components. He sends the pipes to Plumber 3. Plumber 3 welds the components on the steel pipes and adds components to the PVC pipes. He puts the assembled pipes in hydraulic storage containers and stores them, waiting for pickup and delivery to the site. Components and waste from raw materials are stored in waste containers and taken back into the process. Physical waste is systematically accounted for and reused within the assembly process, while any unusable waste is safely disposed of. Prefabricating a PVC pipe takes 15 minutes and 30 seconds, and a steel pipe takes 20 minutes and 30 seconds. The new model has improved space capacity and storage, enabling the handling and assembly of more than one batch of raw materials simultaneously. Work distribution is based on the weight assigned to each steps in the process, allowing for a continuous flow of work without delays.

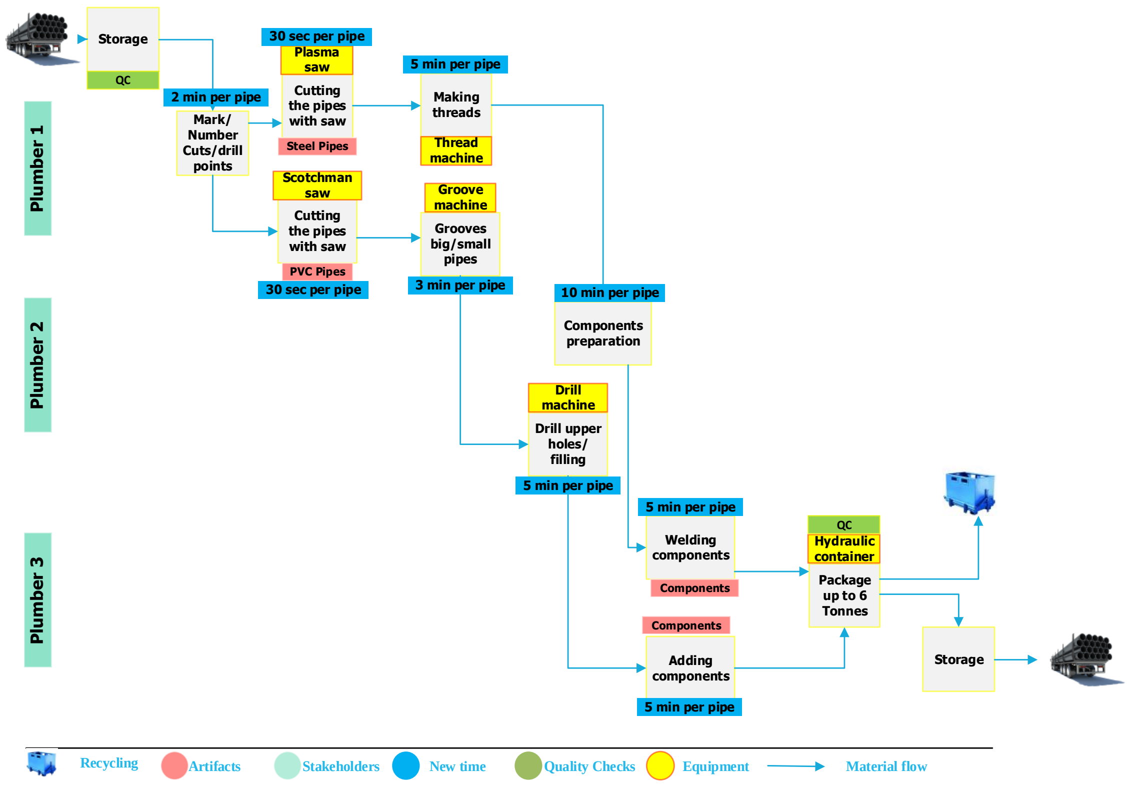
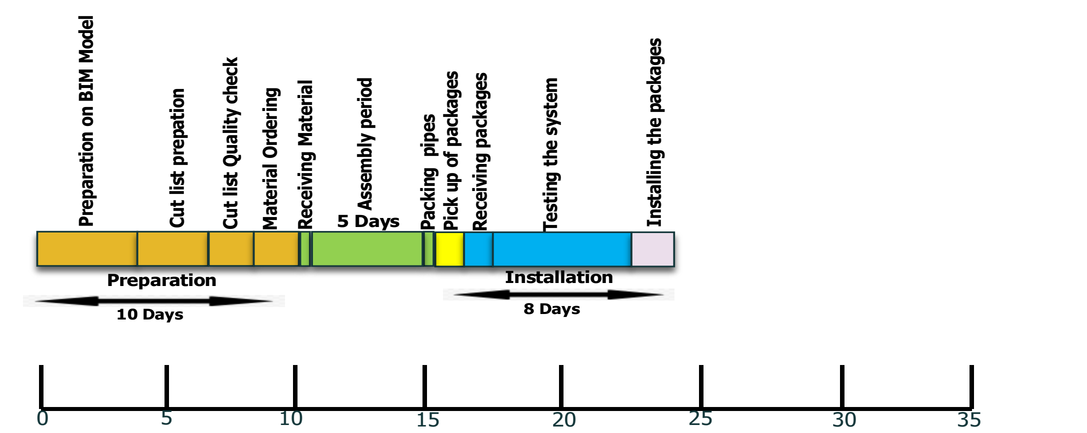


Figure 12: To-Be model for Skytta prefabrication site.

Figure 13 illustrates the estimated time it takes to complete each of the five steps in the assembly process, as well as the estimated cost savings. The preparation, assembly, and installation of prefabricated packages takes 23 days. The proposed CONOPS model in the assembly reduces time 147 hours per consignment of 159 pipes resulting in an estimated cost savings of 44 KNOK. The Ulvenveien office building project requires 13 consignments of prefabricated pipes. This results in a total time savings of 1911 hours and a cost savings of 573 KNOK. To validate the proposed CONOPS model, we considered the factors affecting the prefabrication process and the challenges faced by Bravida AS (Lynghaug et al., 2021). These factors include cost, performance, and manufacturing.



To- Be State

To-Be Assembly time 5th floor	
min per pipe	15.3
6 tons pipe	159
Total time per 6 tons	**2432.7**

To- Be time= 2433/60 = 40.55
Saved Time = As- Is - To- Be
=187.5-40.55 = 146.95
Cost saved = 146.95 * 2.5* 300 =110 KNOK

Item	Meters
Heating	2430
Sprinklers	7610
Cooling	2694
	12734

6 tons in meters	159*6= 954
	12734 /954=13
To-Be	40.55*300 =12165
	12165*13=158145
Building savings	731250-158145
	573105 NOK

Figure 13: Proposed To-Be model workflow process and time calculation.

Table 1 illustrates the cost model that supports the proposed To-Be CONOPS model for the Skytta prefabrication site. It illustrates the total cost for As-Was, As-Is, and To-Be states of the model. Figure A1 in the appendix provides the information flow in different states. Table 1 presents the total Capital and Operational expenditure (OpEx) from the cost model supporting the proposed To-Be CONOPS.

Table 1: Cost Model for Skytta assembly

PHASES		Project A (KNOK)	Project B (KNOK)	Project C (KNOK)	Project D (KNOK)
				Year 1	year 2
		As-Was Onsite	As-Is Skytta Offsite	To- Be Prefabrication	Prefabrication
Capex	Total	108	0	225	0
Opex	G.Total	3585	3312	3081	3076

Table A1 and Table A2 in the appendix provide details and assumptions for the cost model. CaPex refers to the investment cost undertaken by Bravida AS. Regarding onsite construction, the CaPex cost included purchasing and installing an assembly container. Bravida utilized the container as a workshop for pipe assembly and installation. Table 1 shows an OpEx improvement of 273 KNOK from the As-Was state to the As-Is state. Incorporation of prefabrication with a further projected improvement of 231, and 236 KNOK in years 1 and 2, respectively.

The proposed To-Be model's CaPex cost increased the overall cost of year one due to equipment purchasing. However, the equipment bought makes work more efficient for Bravida AS. OpEx refers to the daily cost associated with pipe assembly at Skytta. In the As-Was situation, the OpEx cost was significantly high due to the overhead cost of onsite plumbers, longer fabrication, and installation times.

In the current As-Is situation, labor is still high due to the pain points and there is a challenge of 30% space utilization. Due to the space capacity, they must pack and deliver the assembled packages before commencing new assembly work. This challenge makes the collection of packages into bits, thus increasing transportation costs.

In the To-Be situation, the prefabrication period reduces labor costs, rent, and electricity bills. Utilization of 80% space for prefabrication with 30 % for storage improves work efficiency. We continuously assemble plumbing components, utilizing available space to store raw materials and packages prepared for delivery to the site. Consequently, packages can be stored, picked up, and delivered in higher quantities, significantly reducing transportation costs.

Figure 14 shows a graph representing the cost model totals for the Skytta assembly site, comparing the As-Is scenario as Project B and the To-Be scenario as Projects C and D. Due to sufficient information, we did not include service cost for the new machines in project C.

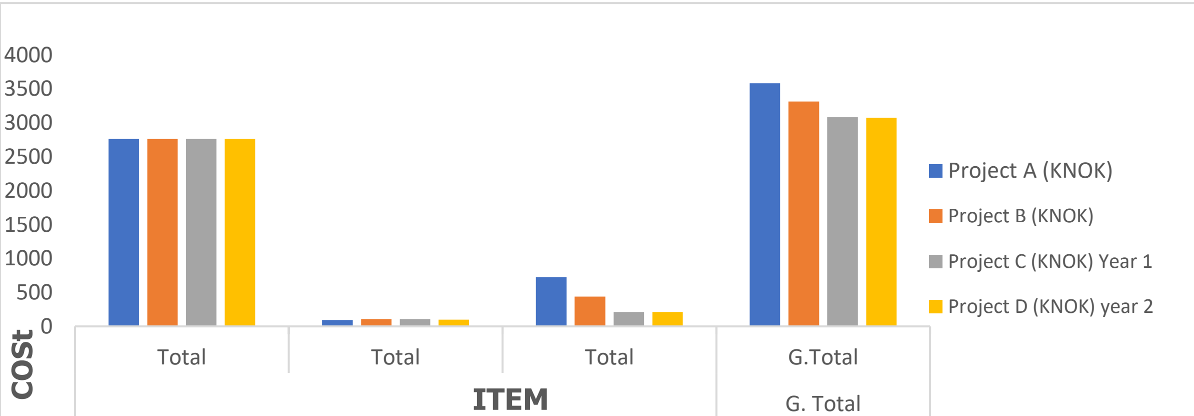


Figure 14:TO-BE Cost Model Scenario

Evaluation

We arranged a meeting with the industry experts to evaluate the research and proposed To-Be CONOPS model. The industry experts included the Project manager (PM) with over five years of experience and the Branch manager (BM) with twenty-five years of experience. We sent the model to stakeholders prior to the evaluation meeting to allow for review and preparation. We included structured questions to guide the evaluation process and assist us in getting feedback to improve the model. Industry experts began their assessment by addressing these structured questions, along with problem statement, research questions, and an analysis of the proposed models. We reviewed their answers thoroughly, discussing each question in detail. Stakeholders provided feedback post-meeting using a scorecard with worse-neutral-better (-, =, +) and their role initials (PM/BM). Table 2 presents the evaluation feedback from the industry experts. This evaluation table shows that the CONOPS integrated into the prefabrication process in plumbing systems has a positive impact.

Table 2: Evaluation of the proposed To-Be CONOPS model.

No	Question	-	=	+	Comments
1	Does the model address the pain points identified in the As- Is state at Skytta?			BM/PM	
2	Do you believe the To-Be model is useful for effective prefabrication in the plumbing segment at Bravida AS?			BM/PM	
3	Does the proposed model meet your expectations in addressing the vision for Bravida AS for prefabrication?			BM/PM	Provides a good point of departure and some good recommendations for rethinking the process and setting up a new more streamlined production-line in a new and better fit location
4	Does the proposed model demonstrate the potential in improving the project delivery times?			BM/PM	
5	Does the proposed model demonstrate the potential in reducing the project deliveries cost?			BM/PM	Provides a very good point of departure for us to develop a more detailed cost/investment proposal. Much easier for the plumbing department to start that process now, as you have analyzed it and pinpointed the pain points and cost savings. They will however need to go more in detail in their budget process.
6	Does the proposed model improve work to labor allocations?		BM	PM	
7	Does the proposed model improve the logistics plan at Skytta?			BM/PM	

Discussion

This study used the CONOPS model as a mapping tool to identify and address challenges faced by Bravida AS in the plumbing process at the Skytta offsite assembly warehouse. The mapping considered key elements: cost, labor, time, and logistics. The study was supported with a cost model according to industry practices and the ISO/IEC/IEEE 29148:2011 standards. The company evaluated both the As-Is and proposed To-Be models and showed potential for improving operations at Skytta. However, further research and validation within the industry are necessary to solidify these findings. The lead researcher collected and analyzed the data from the stakeholders as objectively as possible. However, biases may occur due to the limited number of evaluators. Despite the limitation, the results indicate a positive outcome. Below, we address the research questions for this study based on the proposed To-Be model and its evaluation:

How to develop a CONOPS model to help achieve an effective prefabrication process for plumbing systems in the construction industry? To develop an effective CONOPS model, we first understood the industry context and prefabrication's role in plumbing process. We investigated the state of the art to understand the CONOPS, prefabrication and factors affecting prefabrication of time, labor, cost, and logistics better. We conducted structured interviews with stakeholders, conducted observations, and previewed previous documents. The data collected was crucial in developing a high level As-Is CONOPS that identified the system of interest and mapped the current operations. We developed an As-Is CONOPS for the system of interest and workflow processes from preparation, assembly, installation, and testing highlighting the pain points and inefficiencies within plumbing process. The model included components, artefacts, and documented the As-Is situation, focusing on the pain points using elements of costs and time. Following the ISO/IEC/IEEE 29148:2011 standards, we understood the current situation and identify pain points to address (IEEE, 1998). Later, we proposed a To-Be CONOPS integrated into prefabrication techniques to streamline and address the challenges in the plumbing process focusing on key elements of time, labor, cost, and logistics. The To-Be CONOPS aims to streamline work operations by reducing assembly times, improving space utilization, redistributing works, and implementing standard procedures. Finally, we evaluated the proposed model with industry experts to align with industry standards, for feasibility and practicability.

RQ1: How to develop a CONOPS model to identify pain points in the As-Is state and propose a To-Be plumbing solution state? We identified key stakeholders, the activities they undertake, and their needs. The exploratory method proved effective in understanding the workflow process and challenges faced by Bravida. The state-of-the-art provided the essential aspects for an effective prefabrication process: time, cost, labor, and logistics. The case study served as a base for measuring the elements of prefabrication and potential implementation strategies. We were able to map the workflow process, challenges, and tools, including artefacts, materials, and components. The elements were essential in developing the CONOPS. We compared the As-Is CONOPS with the happy state and saw a 5-day assembly difference. Furthermore, creating a To-Be CONOPS helped us streamline the prefabrication process, leading to an effective solution for the challenges technical contractors face. We recommend first involving a researcher at the project's start to understand the processes, gather information, ask questions, and note the challenges faced. Second, focus on a clearly defined goal, execution plan, and high-level models as a guide. Finally, we evaluated the models with the stakeholders who are industry experts and adjusted the final models.

RQ2: How can prefabrication help reduce project costs regarding physical waste, logistics, and labor? During the plumbing process, technical contractors encountered challenges that led to high project costs. We identified these challenges through the As-Is CONOPS mapping process, supported by a cost model. However, the As-Is CONOPS mapping revealed high labor costs occur due to pain points and improper workflow distribution. The conducted reworks led to high physical waste, labor, and logistics costs. The logistics costs were due to poor utilization of the assembly space. We created a To-Be CONOPS to address the challenges. The To-Be CONOPS introduces standards in the prefabrication process, redistributes the workflow, and improves space utilization. Work is usually distributed among the three plumbers and pace utilization is increased by 80 %. As a result, we reduced labor costs and increased space utilization, allowing for the prefabrication of materials and storage. Rework on site is significantly reduced as with increased space quality checks are properly conducted at the beginning and end of the assembly process. Physical waste is accounted for and re-used in the process, unusable waste is safely disposed of. The cost model shows that prefabrication leads to cost savings of 573 KNOK.

RQ3: How can prefabrication help reduce project delivery times at the construction site? Based on this research, prefabrication is an effective way to reduce project delivery time, especially when it is integrated with a CONOPS in the design phase. The CONOPS demonstrated reduced project delivery times from 35 to 22 working days with a time saving of 1911 hrs. The workflow process demonstrates a reduction in time for the preparation, assembly, and installation phases when prefabrication is utilized. Prefabrication involves standardizing items to be fabricated and completing the work offsite, allowing onsite work to continue as planned. Prefabricated pipes delivered to the site come in packages. The package labeling is for ease of installation and testing. The controlled environment at the prefabrication site is important to meet and ensure quality and standards, reducing the rework timeframe. Prefabrication guarantees that the necessary raw materials are available at the right time and place for an efficient construction process. Identifying and replacing faulty installed pipes during system testing becomes easier, thus reducing the overall delivery time of construction projects.

Conclusion

The study aims to analyze and understand how a technical contractor in the Norwegian construction industry can achieve a more cost effective prefabrication process in their plumbing operations using a CONOPS. We explored the goal based on the challenges of project cost and delivery times in the plumbing processes. We applied a CONOPS to map the workflow process of the offsite assembly warehouse. The case study approach of Skytta assembly as the system of interest showed process flow, and the CONOPS helped us identify the pain points. The pain points affected the process flow, increasing project delivery times and costs. Our research indicates that an integrated CONOPS in a prefabrication process would help reduce project delivery time and costs. The CONOPS is applied in the design phase, allowing early validation, and reducing project risks.

Our proposed solution streamlines workflow processes by reducing project delivery time and costs, with estimated time savings of 1911 hours, translating to a savings of 573 KNOK. The construction process time went down to 12 days in the preparation, assembly installation, and testing phases. We achieved this solution through proper work distribution, increased space utilization to 80%, and eliminating manual work duplication. The results indicated that an integrated CONOPS can enhance the effectiveness and efficiency of the plumbing process in construction projects. The study provides practical insights for stakeholders to adopt more sustainable and efficient construction projects. The knowledge from the CONOPS can be transferred from one department to another, providing a scalable framework for future construction projects.

Future Research

According to (Mostashari et al., 2012), the graphical CONOPS needs to be used in actual test cases to determine its efficiency and effectiveness. In future endeavors, estimating the productivity levels during prefabrication is essential, as this metric will enable labor efficiency assessment. Moreover, integrating digital tools into the proposed To-Be CONOPS is essential to enhance operational efficiency and minimize preparation time. These digital tools are instrumental in facilitating the timely initiation of prefabrication processes. For the technical contractor, we recommend building prefabrication capabilities while assessing the potential of the proposed CONOPS. Moreover, due to stakeholders' ever-changing needs and design, it is crucial to understand the right level of prefabrication.

Acknowledgements

We want to express our gratitude to the management and employees of Bravida AS, whose support and valuable input have been instrumental in this research.

References

Dallasega, P., Revolti, A., Schulze, F., & Martinelli, M. (2021, november 11). *Augmented Reality to Increase Efficiency of MEP Construction: A Case Study*. https://doi.org/10.22260/ISARC2021/0063

George, T. (2021, desember 3). *Explanatory Research | Definition, Guide, & Examples*. Scribbr. https://www.scribbr.com/methodology/explanatory-research/

Gunawardena, T., & Mendis, P. (2022). Prefabricated Building Systems—Design and Construction. I *Encyclopedia* (Bd. 2, s. 70–95). https://doi.org/10.3390/encyclopedia2010006

Heating and plumbing servicing. (2023). Bravida. https://www.bravida.se/en/our-offering/heating-and-plumbing/heating-and-plumbing-service/

IEEE. (1998). *IEEE Guide for Information Technology—System Definition—Concept of Operations (ConOps) Document*. IEEE. https://doi.org/10.1109/IEEESTD.1998.89424

Industry, M. of T. and. (2001, juni 28). *Business and industry in Norway—The building and construction industry* [BrosjyreVeiledning]. 024001-120054; regjeringen.no. https://www.regjeringen.no/en/dokumenter/Business-and-industry-in-Norway---The-building-and-construction-industry-/id419366/

Jannasch, E. (2012). Logistical aspects of Prefabrication. *INDUSTRY INNOVATION*.

Kamali, M., Hewage, K., & Sadiq, R. (2019). Conventional versus modular construction methods: A comparative cradle-to-gate LCA for residential buildings. *Energy and Buildings*, *204*, 109479. https://doi.org/10.1016/j.enbuild.2019.109479

Korfiatis, P., Zigh, M., & Blackburn, M. R. (2012). *Graphical CONOPS Development to Enhance Model Based Systems Engineering*.

learnorg. (2024). Plan, Do, Check, Act (PDCA)—A Resource Guide. *Lean Enterprise Institute*. https://www.lean.org/lexicon-terms/pdca/

Lee, Y., Kim, J. I., Khanzode, A., & Fischer, M. (2021). Empirical Study of Identifying Logistical Problems in Prefabricated Interior Wall Panel Construction. *Journal of Management in Engineering*, *37*(3), 05021002. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000907

Li, X., Li, Z., & Guangdong, W. (2017). Modular and Offsite Construction of Piping: Current Barriers and Route. *Applied Sciences*, *7*, 547. https://doi.org/10.3390/app7060547

Lynghaug, T. F., Kokkula, S., & Muller, G. (2021). Implementing Systems Engineering in the Construction Industry: Literature Review for Research Alignment. *2021 16th International Conference of System of Systems Engineering (SoSE)*, 150–155. https://doi.org/10.1109/SOSE52739.2021.9497464

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., & Wang, X. (2016). Cost analysis for sustainable off-site construction based on a multiple-case study in China. *Habitat International*, *57*, 215–222. https://doi.org/10.1016/j.habitatint.2016.08.002

Market research. (2024, mars 20). *Norway Construction Market Summary, Competitive Analysis and Forecast to 2027*. marketresearch.com. https://www.marketresearch.com/MarketLine-v3883/Norway-Construction-Summary-Competitive-Forecast-34452263/

Mordorintelligence. (2023). *Scandinavia Prefabricated Housing Market Size & Share Analysis—Industry Research Report—Growth Trends*. /www.mordorintelligence.com

Mostashari, A., Mccomb, S., Kennedy, D., Cloutier, R., & Korfiatis, P. (2012). Developing a stakeholder-assisted agile CONOPS development process. *Systems Engineering*, *15*, 1–13. https://doi.org/10.1002/sys.20190

Seaker, R., & Lee, S.-H. (2006). Assessing Alternative Prefabrication Methods: Logistical Influences. I M. Pandey, W.-C. Xie, & L. Xu (Red.), *Advances in Engineering Structures, Mechanics & Construction* (s. 607–614). Springer Netherlands. https://doi.org/10.1007/1-4020-4891-2_51

SEBok. (2023). *Concept of Operations (ConOps)*. https://sebokwiki.org/wiki/Concept_of_Operations_(ConOps)_(glossary)

Shehata, M. E., & El-Gohary, K. M. (2011). Towards improving construction labor productivity and projects' performance. *Alexandria Engineering Journal*, *50*(4), 321–330. https://doi.org/10.1016/j.aej.2012.02.001

Shih, K. C., Huang, C. N., Liu, S. S., Wu, T. S., & Wang, M. T. (2005). *Study on the storage and transportation optimization of prefabrication factory*.

Statista. (2023). *Forecast: Industry revenue of "plumbing, heat and air-conditioning installation" in Norway 2012-2025*. Statista. https://www.statista.com/forecasts/394425/plumbing-heat-and-air-conditioning-installation-revenue-in-norway

Statistics Norway. (2024, februar 21). *Population in Norway*. SSB. https://www.ssb.no/en/befolkning/folketall/statistikk/befolkning

Tavares, V., Soares, N., Raposo, N., Marques, P., & Freire, F. (2021). Prefabricated versus conventional construction: Comparing life-cycle impacts of alternative structural materials. *Journal of Building Engineering*, *41*, 102705. https://doi.org/10.1016/j.jobe.2021.102705

The Bravida Way. (2023). Bravida. https://www.bravida.no/om-bravida/the-bravida-way/

Verma, W. J. L., Doug Kirkpatrick, Jerry Jon Sellers, Dale Thomas, and Dinesh. (2014). *Applied Space Systems Engineering: Wiley J. Larson, Doug Kirkpatrick, Jerry Jon Sellers, Dale Thomas, and Dinesh Verma*. https://www.book2look.com/book/HePl1WNupS

Xing, W., Hao, J. L., Qian, L., Tam, V. W. Y., & Sikora, K. S. (2021). Implementing lean construction techniques and management methods in Chinese projects: A case study in Suzhou, China. *Journal of Cleaner Production*, *286*, 124944. https://doi.org/10.1016/j.jclepro.2020.124944

Yan, G., Yang, Y., Zhang, H., Li, Z., Chen, S., Zhao, X., Sun, Z., Fan, X., Zhang, M., Huang, L., & Liu, L. (2024). A Review of Life Cycle Construction Process and Cutting-Edge Technology in Prefabricated MEP Installation Engineering. *Buildings*, *14*, 630. https://doi.org/10.3390/buildings14030630

Yi, W., Wang, S., & Zhang, A. (2019). Optimal transportation planning for prefabricated products in construction. *Computer-Aided Civil and Infrastructure Engineering*, *35*. https://doi.org/10.1111/mice.12504

Yin, R. K. (2017). *Case Study Research and Applications: Design and Methods*. SAGE Publications.

Appendix

Table A1 Cost Model for Skytta assembly.

	PHASES		**Project A (KNOK)**	**Project B (KNOK)**	**Project C (KNOK)**	**Project D (KNOK)**
	Year				Year 1	year 2
CAPEX			**As-Was Onsite**	**As-Is Skytta Offsite**	**To- Be Prefabrication**	**Prefabrication**
	Assets					
		Storage Container	108			
		Scotchman saw			121	
		Plasma saw			90	
		Transport Container			14	
		Total	108	0	225	0
	PHASES		**Project A (KNOK)**	**Project B (KNOK)**	**Project C (KNOK)**	**Project D (KNOK)**
OPEX	**Year**				Year 1	year 2
	Raw Material	Pipes	2360	2360	2360	2360
		Components	18	18	18	18
		Bends	181	181	181	181
		Valves	132	132	132	132
		Joints	73	73	73	73
		Total	2764	2764	2764	2764
	Transport					
		To skytta		89	89	89
		To site	95	18	15	10
		Total	95	107	104	99
	Assembly					
		Labour				
		Skytta		45	22	22
		Site	726	242	113	113
		Electricty		15	8	8
		Rent		140	70	70
		Total	726	441	213	213
		G.Total	**3585**	**3312**	**3081**	**3076**

Table A2 Cost Model assumptions

	Assumptions:	**NOK**	**UNITS**	**Description**
1	Labor per skilled plumber	238.00		per hour
2	Labor per regular plumber	215.00		per hour
3	Plumbers on site (As-was)		15	plumbers
4	Plumbing duration (As-Was)		30	days
5	Plumbers at Skytta (As-Is)		2.5	plumbers
6	Plumbers on site (As-Is)		10	plumbers
7	Plumbing duration (As-Is)		15	days
8	Plumbers at Skytta (To-Be)		2.5	plumbers
9	Plumbers on site (To- Be)		7	plumbers
10	Plumbing duration (To-Be)		10	days
11	Percent given for Uleivenvein project		40%	
12	Semi assemlby unit for assembly and storage onsite	108000		
13	Electricty 40% of the main cost	15200		
14	Rent 40% of the main cost	139600		
15	Feedback loops (time*labour)			
16	Rework (time*labour)			
17	Skytta assembly (To-Be)		5	Days
18	Skytta assembly (As -Is)		10	Days
19	Electricty 20% of the main cost (Prefab)	7600		
20	Hours worked per day by plumbers		7.5	hours
21	Rent 20% of the main cost (Prefab)	69800		

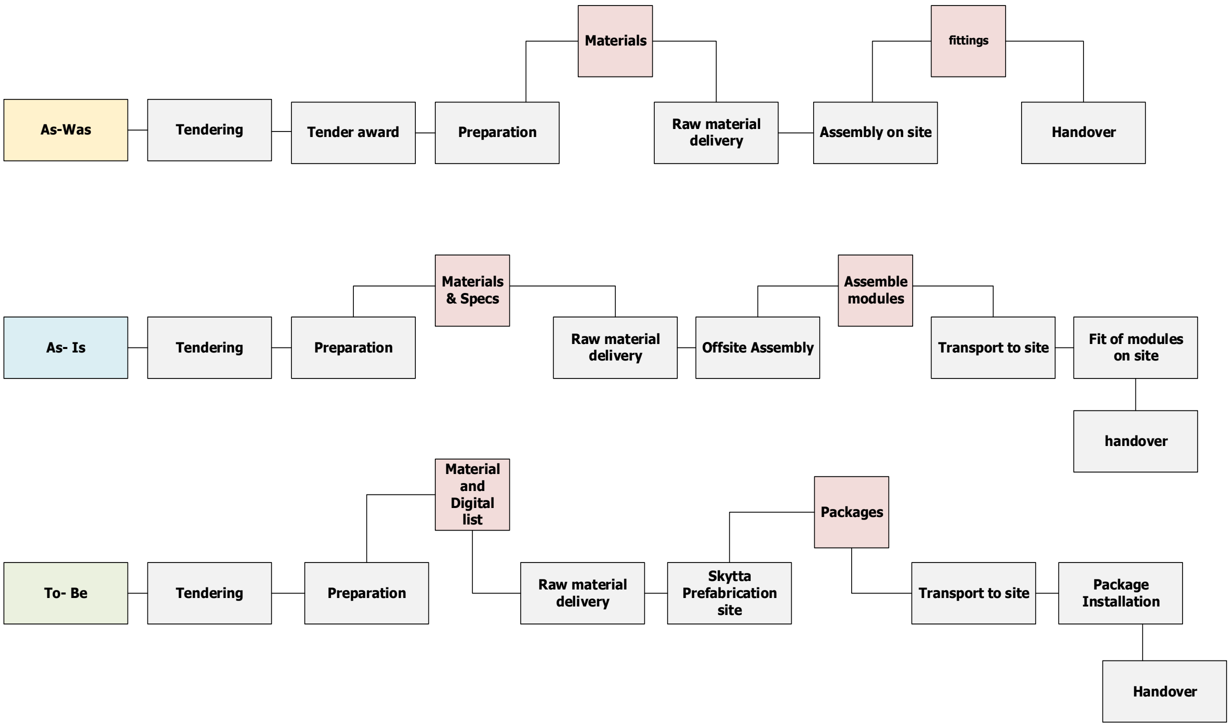


Figure A1. High level CONOPS of As-Was, As-Is and To-Be guide.

Biography

Karl Martins Obote originally from Kenya, is a Management Trainee at Klinger Westad, specializing in Data Analytics, Technical Purchasing, and Continuous Improvement. He holds an MSc in Innovation and Technology Management with Systems Engineering specialization from the University of South-Eastern Norway (USN), as well as a degree in Business Administration and Management degree from St. Paul's University, Kenya. During his studies at USN, Karl served as Project Manager for Sprout USN, where he demonstrated his leadership skills. He has also held roles in logistics and warehouse operations, contributing to process optimization. Karl is currently pursuing higher studies in Applied Machine Learning at Noroff University College. He was awarded the Sustainability Award with his team at Kongsberg Group Your Extreme 2023.

Gerrit Muller originally from the Netherlands, received his master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as manager systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008, he became a full professor of systems engineering at University of South-Eastern Norway in Kongsberg (USN), Norway. He continues to work as a senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position. Since 2020, he is an INCOSE Fellow and Excellent Educator at USN.

Satyanarayana Kokkula received his PhD from the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. From 2006 to 2016, he served as a Specialist Engineer in Structural Analysis at FMC Kongsberg Subsea AS. In August 2017, Dr. Kokkula joined the University of South-Eastern Norway (USN) as an Associate Professor of Systems Engineering. He currently serves as the Program Coordinator for the Master's degree in Systems Engineering and oversees the Systems Engineering specialization for the Innovation and Technology Management Master's degree at USN. Dr. Kokkula is a Certified Systems Engineering Professional (CSEP) by the International Council on Systems Engineering, and a Senior Member of the Institute of Electrical and Electronics Engineers.

Tobias Fredrik Lynghaug earned his mechanic certificate in 2011, followed by a BSc in Mechatronics from the University of Agder in 2017. He later completed a Master's degree in Systems Engineering with Industrial Economics from the University of South-Eastern Norway in 2021. During his master's studies, in 2019 he joined Bravida as a Systems Engineer and Project Manager. In 2022 he was promoted to Head of PMO Oslo, continuing to provide services like Project Management, Design Management, Systems Engineering, Planning, Cost control, and Quality Assurance, for their large projects.