D4.3 DIGITAL TWIN SUPPORTED LEAN PROJECT PLANNING, CONTROL, AND RISK MANAGEMENT

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ABSTRACT

There is a considerable opportunity to improve the planning and control of construction work. The construction industry is still struggling to adopt to the digital revolution's concepts due to complexity, uncertainty, the fragmented supply chain, the short-term thinking, and the culture of ad hoc solutions. The main purpose of this document is to describe the business and decision-making processes to support lean project planning, control, and risk management with digital twin data.

Additionally, this document also presents and describes a process model that has been developed for the construction phase. In this task, three demo-sites have been investigated. All three projects were building construction projects hence no infrastructure projects have been researched. To describe the designed process model, IDEF0-notation was used. A vital part of using digital twins to support process management and agile planning is the capture of data from the site.

The produced process model contains five different process groups: initiating, planning, implementing, controlling, and closing and is generally based on the demonstration sites within the ASHVIN project and applicable to constructions sites worldwide. From each demonstration site information was gathered considering how data-collection had been conducted on each site using various digital tools and how they corresponded to the different KPI's within the project. The methods were then analysed and evaluated how they could be implemented in a work breakdown structure (WBS) and location breakdown structure (LBS). These methods in combination with the process model allows the team to detect issues, react and adjust the schedule to make the whole process smoother. It can assist them in planning when to take in certain disciplines and when to order materials.

During this task the demonstration projects were already in the construction phase, which meant that it was mainly controlling activities that could be conducted according to the process model. It would be interesting to be able to test the process model from the beginning of a construction project, in other words from the initiating phase. Multiple findings have been made throughout this study. The main takeaway from is how vital it is for a project to decide in an early stage the prerequisites that will be needed to control and affect the project during the construction phase. This is the reason why it is essential to make sure that the process model as well as the digital tools are applied in depth. The second point to be made is to understand that all the KPI's mentioned in the results section can be collected using a multitude of different tools and methods.

As given in the Grant Agreement (Annex I (part A), page 24), this report has met its main purpose of describing the business and decision-making processes to support lean project planning, control, and risk management with digital twin data.

KEYWORDS

Digital twin, Lean Project Management, Work Breakdown Structure, Location Breakdown Structure

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DISCLAIMER

ACRONYMS & DEFINITIONS

DS	Daily schedule
LA	Look Ahead
LBS	Location Breakdown Structure
MS	Monthly Schedule
Smart Factory	A digitised manufacturing facility that uses connected devices, machinery, and production systems to continuously collect and share data
SmartHelmet	An Internet of Things (IoT) device that collects and syncs data to a digital twin
WBS	Work Breakdown Structure
WS	Weekly Schedule
KPI	Key Performance Indicator
PI	Performance Indicator

ASHVIN PROJECT

ASHVIN aims at enabling the European construction industry to significantly improve its productivity, while reducing cost and ensuring absolutely safe work conditions, by providing a proposal for a European wide digital twin standard, an open-source digital twin platform integrating IoT and image technologies, and a set of tools and demonstrated procedures to apply the platform and the standard proven to guarantee specified productivity, cost, and safety improvements. The envisioned platform will provide a digital representation of the construction product at hand and allow to collect real-time digital data before, during, and after production of the product to continuously monitor changes in the environment and within the production process. Based on the platform, ASHVIN will develop and demonstrate applications that use the digital twin data. These applications will allow it to fully leverage the potential of the IoT based digital twin platform to reach the expected impacts (better scheduling forecast by 20%; better allocation of resources and optimization of equipment usage; reduced number of accidents; reduction of construction projects). The ASHVIN solutions will overcome worker protection and privacy issues that come with the tracking of construction activities, provide means to fuse video data and sensor data, integrate geo-monitoring data, provide multi-physics simulation methods for digital representing the behaviour of a product (not only its shape), provide evidence-based engineering methods to design for productivity and safety, provide 4D simulation and visualization methods of construction processes, and develop a lean planning process supported by real-time data. All innovations will be demonstrated on real-world construction projects across Europe. The ASHVIN consortium combines strong R&I players from 9 EU member states with strong expertise in construction and engineering management, digital twin technology, IoT, and data security / privacy.

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1 INTRODUCTION

1.1 Background

There is a considerable opportunity to improve the planning and control of construction work. The construction industry is still struggling to adopt to the digital revolution's concepts due to complexity, uncertainty, the fragmented supply chain, the short-term thinking, and the culture of ad hoc solutions. Construction projects are complex due to the involvements of many stakeholders and fact that each project is considered unique. The level of uncertainty of a project is also affected by its unpredictable environment adding complexity to the project. The fragmented supply chain and short-term thinking of construction companies have limited capabilities where the short-term nature of construction projects is an obstruction to innovation. In addition, the culture of the construction industry is known for its reluctant practices in adaptation (Alaloul et al., 2020).

Work during the construction phase is mainly conducted by subcontractors as the main contractors rely on many subcontractors. As much as 90 per cent of the construction work is carried out by a variety of subcontractors while the main contractor tends to focus on management and coordination. In addition to this, multiple subcontracting firms are small because the contractors tend to employ pyramid subcontracting by using multiple tiers of subcontractors. This type of working structure consequently makes the sub-contractors unable to adopt modern principles of quality management (Karim, Marosszeky, & Davis, 2006).

Looking at today's scheduling practice for construction work shows that planning for workflow is deficient due to practical and methodological reasons. Focus is mainly placed on the planning of transformations. Flow management is not explicitly addressed but is rather being realised as a side-product of short-term task management. In addition, today's scheduling techniques provide limited insight into the spatial configuration of construction operations, thereby limiting the communication among project stakeholders and, as a result, limiting the planning and control of workflow (Jongeling, 2006).

1.2 Purpose of the document

The main purpose of this document is to describe the business and decision-making processes to support lean project planning, control, and risk management with digital twin data (Grant Agreement, Annex I (part A), page 24)**.** Additionally, this document also presents and describes a process model that has been developed for the construction phase. The process aims to create a planning tool that a person working with lean project planning. It is not aimed for a specific role at a site but mainly to simplify the planning process for anyone involved. The developed model is based on standard ISO 21500:2012 which guides project management. The standard includes process groups such as initiating, planning, implementing, controlling, and closing (ISO 21500:2012). The process groups and their relationships to each other are shown in Figure 1 below.

The referred groups for this document are consortium partners of the ASHVIN project but the target group of this process is any project interested in this way of planning (tool developers and partners responsible for the demonstrations sites).

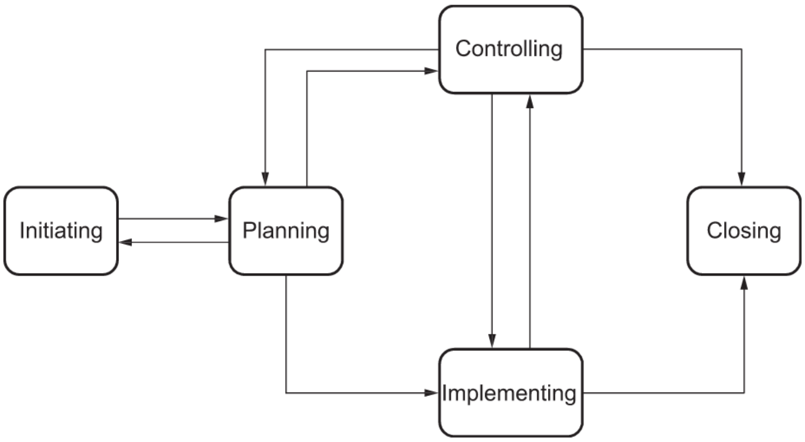


Figure 1. Process groups interactions (ISO 21500:2012).

The goal is for the reader to gain a wide understating of the tools and types of data that could be collected. Furthermore, understand how the data in question could be used in the process presented to make decisions to increase efficiency, productivity, and safety on sites.

1.3 Structure of the document

The document is structured into five chapters. In the first section relevant literature is presented. The second section contains a description of the methods used to conduct work within the task and is followed by the third section where results and analysis is presented. The fourth section reviews the work that has been made including the results. In the fifth and sixth section conclusions are drawn, and further research suggested.

1.4 Delimitations

In this task, three demo-sites have been investigated. All three projects were building construction projects hence no infrastructure projects have been researched. For the conducted work the ISO 21500:2012 standard has been used as a foundation and therefore results are shaped to fit the standard.

The digital tools that have been analysed are limited to tools used on the demonstration sites in Rinteln, Barcelona and Gothenburg. This is due to the ability to test and analyse the tools on a selected sites as the study progresses.

But it should be pointed out that the tools that have been analysed have not been restricted within the tools of Ashvin. Any tool that a demo site recommends for a specific KPI has been taken into consideration regardless of if it was developed within the Ashvin project or not.

1.5 Demo sites

1.5.1 Barcelona, Spain

Mile is a reinforced concrete office building with long-spanned slabs. The construction of this building is heavily controlled and dependent of the slab deformation and serviceability limit states. The building is located in Barcelona and is a part of project 22@, also known as 22@Barcelona and "Innovation district" ("Districte de la innovació").

Figure 2. View from the street (Universitat Politecnica de Catalunya, 2021)

1.5.2 Gothenburg, Sweden

The Kineum case is a high-rise building located in the city of Gothenburg, Sweden, see figure 3. The project started in 2019 and ends in summer of 2022. It consists of 30,000 m2, 960-1,400 m2/floor and has 27 floors. Once completed it will have a height of 110 meters. Once finished the building is supposed to host both offices and a hotel business.

Figure 3. Construction process of Kineum project in Sweden (NCC, 2021).

1.5.3 Rinteln, Germany

The demo site is an industrial building located in Rinteln, Germany. The building will host state-of-the-art production facilities to ensure a Smart Factory. It consists of four different halls with a height of 12 meters. Hall 1 and hall 2 forming one building part, which will be used for production of food packaging. Hall 3 and hall 4 forming the other part for storage and logistics. Overall, the building has a size of nearly 30,000 m², while halls 1 and 2 utilise one third. The structure of the building consists mainly of prefabricated components such as precast concrete pillars, steel walls, and steel roof panels.

1.6 Key Performance Indicators

Key performance indicators (KPI: s) in the ASHVIN project have already been defined and presented in a previously published deliverable, *D4.1*, within the project.

The key performance indicators are productivity, resource efficiency and safe construction work. These constitute of various performance indicators (PI: s) which are quantifiable and measurable sub-criteria of a KPI, see figure 4.

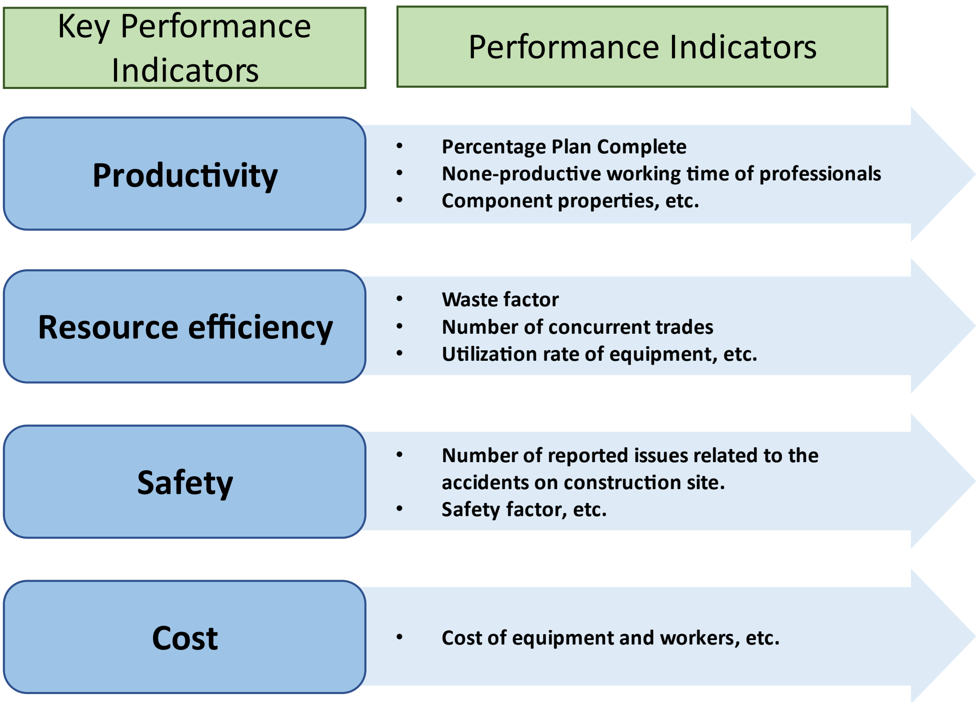


Figure 4. Definition of Key Performance Indicators and Performance Indicators for ASHVIN project.

Their role is to represent four main objectives that a site bases decisions and planning on, and they act as the pillar stones in this report. The tools that are analysed in this report are reviewed based on these four aspects and how well the tools can contribute within these four focus areas.

1.7 Relations within Ashvin

Ashvin consists of multiple work packages, deliverables, and task. All these task and deliverables are connected by the project Ashvin, but it might not be always clear how they are connected. Task 4.2 is a report describing the formalisms developed in the project to simulate construction progress using stochastic digital twin data. This type of discrete event simulation has been taken into aspect in this deliverable and this will be presented later in the report.

Task 4.5 has also acted as an inspiration and support in this report due to its focus on developing configuration management processes and how to illustrate them. Task 4.5 and 4.3 have a common ground regarding the management processes.

A tool is also being developed in the Ashvin project called DES. DES is a Simulation-based real-time construction site and logistic planning tool that will expectedly go hand in hand with this presented process model. The main goal is for some of the tools and processes presented in this report to be implemented into this DES tool to have a place for visual data information.

1.8 Outline of the report

This report is divided up into a few sections. The first part of the report focuses on the backstory of the project Ashvin and the demo sites that will be used as examples and collection of data from.

Further down in the second section of the report a literature study is carried out to present concepts, tools, and other relevant information regarding the process model in mind. Then the methodology of how the process was created and as well as how the demo sites have contributed to the process model.

A great part of the report is focusing on the process itself, regarding the steps that should be taken in the process and how the tools could contribute to the process. The tools used and presented by the different demo sites are analysed based on how they could contribute to the process and in what way, if it is a location based or activity-based kind of data. At the end of this section in the report a step-by-step theoretical example of the process is presented based on the tools and datatypes presented in this report.

An discussion regarding the applicability of the process model outside the demo cases of the Ashvin project as well as the use of other tools to collect data. And the report ends with a conclusion regarding the study and its domain results, and future studies.

2 THEORY

In this section, relevant theory is presented for the work conducted within this task. Initially concepts such as lean construction is presented and is then followed by information about various digital tools and lastly two different breakdown structures and scheduling methods are presented and described.

The concepts of process management and models, lean construction and IDEF0 technique are in this report combined to reach the desired process model that is presented in the results.

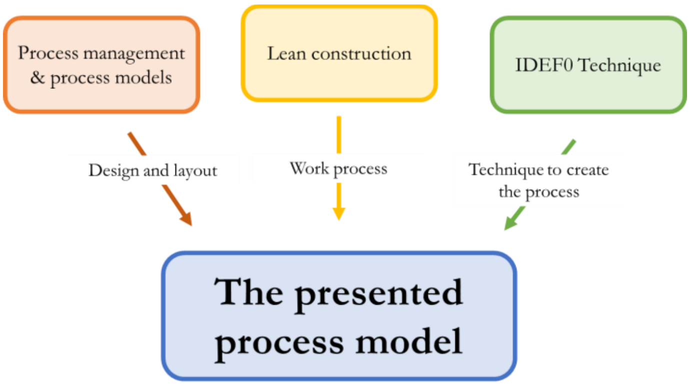


Figure 5: How the different concepts attributed to the resulted process model.

2.1 Process management and process models

The purpose of business process management is to capture, understand and improve work within organisations, by using process models as a central tool (Smirnov et al., 2012). Business process models play a pivotal role in representing how work is conducted in organisations (Smirnov et al., 2012) and can give an understanding of the inner processes (Aguilar-Savén, 2004).

To describe the designed process model, IDEF0 was used. IDEF0 is a structured technique that combines graphical language with text-based descriptions. Each process in a system is represented with a rectangular box and the relationships of the boxes are shown by arrows (Tanyer & Aouad, 2005). An example of a process model produced with the IDEF0 technique can be seen in figure 6 below.

The process management and process model are a way to present a workflow, and this has acted as an inspiration in this report regarding how a workflow could be presented, see figure 5.

2.2 Lean construction

Lean Construction is to a great extend an adaptation and implementation of Japanese manufacturing principles within the construction process. Even though the guiding principles were not formulated until after nearly ten years of research and application, but you could assume that from the beginning they were: While delivering the project, maximize the value for the client and minimize the waste (Bertelsen, 2004).

Koskela suggests a Transformation Flow Value (TFV) understanding of construction, based on principles from the manufacturing industry (Koskela, 1992). The transformation view of production has been dominant in construction, which is based on the idea that a combination of production factors results in a finished product. Workflow is defined as the movement of tasks through a work process (Hopp &

Spearman, 1996). The transformation concept is considered limited in the sense that this view does not recognize that there are other phenomena in production than transformation. The transformation view is not especially helpful in figuring out how resources are used the flow view of production identifies four stages – processing, inspection, waiting and moving – of which only the processing stage is transformation, the others are not (Koskela L. , 1999).

Lean construction has been used in this report as a way of thinking in a process. How a decision can be evaluated, tested, and then influence later decisions in the process, see figure 5.

2.3 Decisions making process by using IDEF0 technique

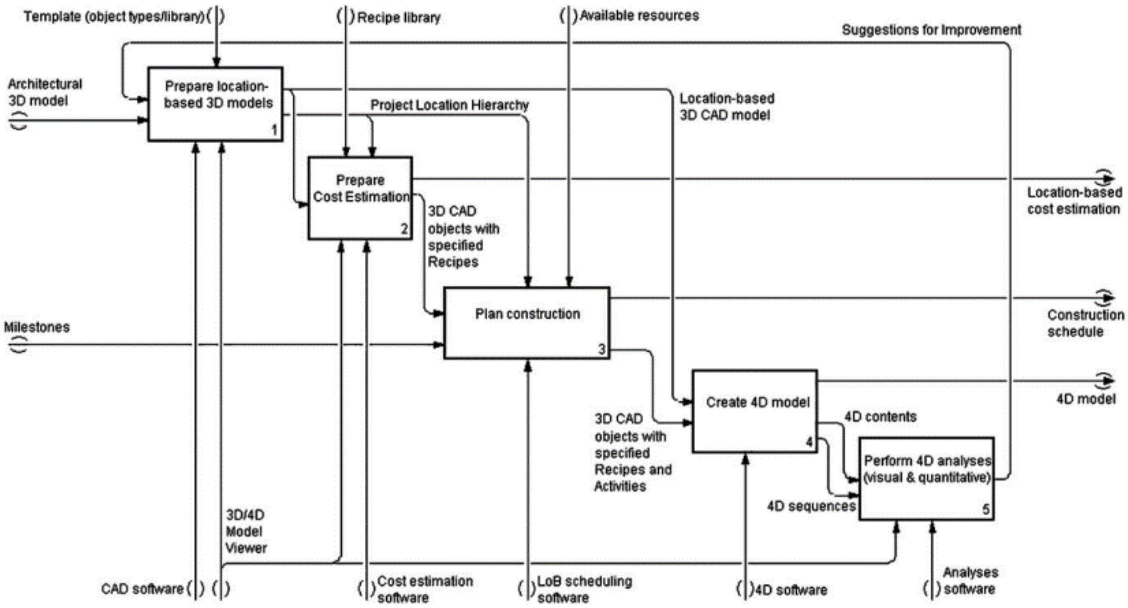


Figure 6:Information flow shown with IDEF0 technique, (Jongeling & Olofsson, 2006) .

On site risk management in construction is a daily activity that needs to be altered as the process is advanced by time. There are a lot of factors that need to be included in the decisions and it might not always be the easiest to do. IDEF0 could be a tool that might simplify this process due to its use in computer integrated industries to simplify communication and productivity, (Liles & Presley, 1995).

IDEF0 which has ha focus to make use of digital tools that in this case could be assumed would be to “Prepare location-based digital twin models” of some sort, having data integrated into it. As seen in figure 6, the IDEF0 technique has been used in Jongeling and Olofsson report to understand what information is needed when in the decision process (Jongeling & Olofsson, 2006). This could be a way to make use of the IDEF0 technique as well in this case. The four squares represent the four major activities in the process and the arrows which in a IDEFO technique called “Manufacturing Function”. The arrows surrounding the squares represent different types of data that act as input, Controls, Mechanics, and outputs based on what side they enter or leave form the box in question, (IDEF, 2022).

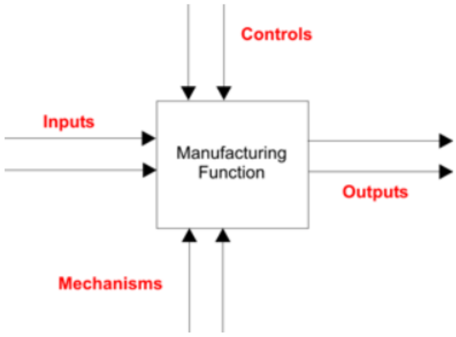


Figure 7: Visualisation regarding the IDEF0 technique, (IDEF, 2022).

The five major activities would be based on figure 7 to be Prepare location-based Digital Twin models, Prepare cost estimation, Plan construction, Create 4D model and Preform 4D analysis (Jongeling & Olofsson, 2006).

The IDEF0 technique shows how different components can affect a function/decision and how the process proceeds over time. This has been acting as an input and inspiration when forming the process resulted in this report, see figure 5. Through this technique, the management process can be supported with real-time data in a digital twin environment.

2.4 Tools that could be used to gather data at a site

A vital part of using digital twins to support process management and agile planning is the capture of data from the site, preferably obtaining real-time data over time. This section gives a handful of technologies and methods available for this.

2.4.1 Laser scanner

A laser scanner produces a large number of 3D points which results in a three-dimensional colour point cloud which can be used to extract CAD elements or by using point triangulation creating a 3D surface model (Haddad, 2011). The sensor measure distances between the sensor emitting a laser pulse and the surface, which is intercepted by the laser's cone, thus returning the 3D coordinate of the position of that point on the surface (Pirotti et al., 2012). Laser scanners are widely used in the field of architectural, archaeological, and environmental surveying (Haddad, 2011).

2.4.2 Drone and robots

A drone can be defined as an unmanned aircraft or ship guided by a remote control or computers (Tang & Shao, 2015). Sensors can be mounted on the drone such as accelerometers, gyroscopes, GPS and barometers for positional measurements (Ahirwar et al., 2019). Cameras are also frequently mounted for navigation and aerial photography (Ahirwar et al., 2019). The fastest growing commercial adopter of drones is the construction industry where the usage skyrocketed during 2017 with 239% (DroneDeploy, 2018).

2.4.3 Accelerometer

Acceleration is defined as the change in velocity over time (Freedson et al., 2005). Accelerometers measure acceleration multiple times within a given frequency and summarize this as a count over a pre-specified time period or epoch (Evenson & Terry, 2009).

2.4.4 360 cameras

Unlike a traditional perspective camera, which samples a limited field of view of the 3D scene projected onto a 2D plane, a 360° camera captures the entire viewing sphere surrounding its optical centre, providing a complete picture of the visual world (Su & Grauman, 2017). 360° cameras are gaining popularity as part of the rising trend of virtual reality (VR) and augmented reality (AR) technologies, and will also be increasingly influential for wearable cameras, autonomous mobile robots, and video-based security applications (Su & Grauman, 2017).

2.4.5 Multi-sensor

Since a single sensor generally can only perceive limited partial information about the environment, multiple similar and/or dissimilar sensors are required to provide sufficient local pictures with different focus and from different viewpoints in an integrated manner (Xiong & Svensson, 2002). The benefits of multi-sensor systems are to broaden machine perception and enhance awareness of the state of the world compared to what could be acquired by a single sensor system (Xiong & Svensson, 2002). A multisensory allows multiple measurements to be conducted simultaneously, values such as temperature, particles, and moisture et cetera.

2.4.6 Temperature sensor

As one of the fundamental thermodynamic properties, temperature is an important parameter to be measured in manufacturing processes, environment monitoring, structural safety protection, and agriculture and food production. Based on the nature of contact, temperature sensing techniques can be classified as either invasive, non-invasive, or semi-invasive (Sanders, Yao, & Huang, 2015).

Invasive temperature sensors are usually installed on or near a component of interest. A cable has to be used to connect the sensor to the measurement instrument. Two examples of such temperature sensors are thermocouples and optical fiber temperature sensors. A major drawback of invasive temperature sensing techniques is that the cable connections could incur high installation and maintenance costs, especially for high temperature sensing applications. In contrast, non-invasive temperature measurement techniques, such as infrared thermography and acoustic thermography, can remotely measure the temperature of a medium without any physical contact. However, non-invasive techniques usually require expensive and high precision instruments. For semi-invasive temperature sensing, the temperature sensor is installed on the component of interest and the temperature readouts are carried out remotely (Sanders, Yao, & Huang, 2015).

2.5 Work breakdown structure

The work breakdown structure (WBS) is the process of dividing a project's overall work into several more manageable hierarchy structured tasks (Siami-Irdemoosa, Dindarloo, & Sharifzadeh, 2015). In the hierarchy structure, the upper levels are ordered into groups that are logical and are followed by the lower levels (Siami-Irdemoosa, Dindarloo, & Sharifzadeh, 2015). The lowest level is the component of the WBS that can be scheduled, and its costs can be estimated, monitored, and controlled (Siami-Irdemoosa, Dindarloo, & Sharifzadeh, 2015). An example of a work breakdown structure is shown below in figure 8. In this example the construction project has been divided in to three different sections, internal, foundation and external with multiple elements connected to them.

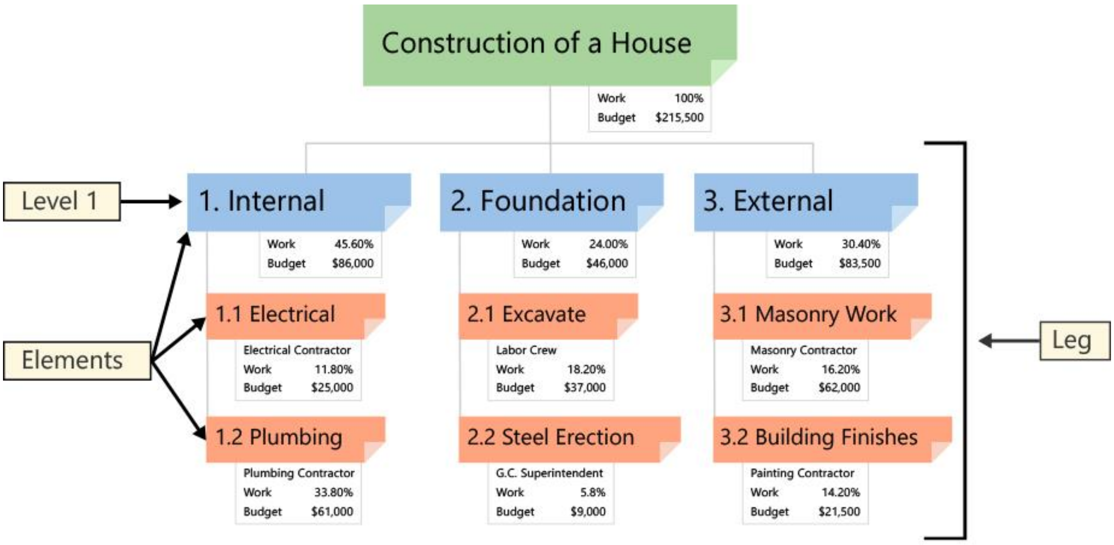


Figure 8: Example of a work breakdown structure for construction of a house (Workbreakdownstructure.com, n.d.).

2.6 Location breakdown structure

A location breakdown structure (LBS) can be defined as a theoretical and hierarchical description of a project and allows schedulers to allocate and group activities or tasks across locations (Janssen, 2014). An example of an LBS can be seen in figure 9 where a building is divided into floors and then into the apartments on each floor. It is not a building information model (BIM) but rather a methodology for interacting with a BIM, placing demands on the BIM for both properties and characterisation (breakdown) (Russell & Harfield, 2014).

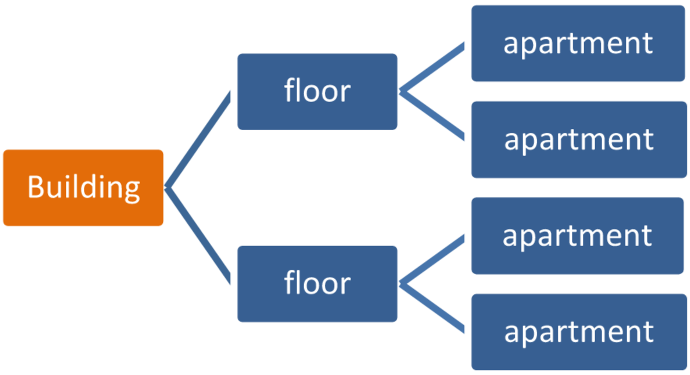


Figure 9: Concept of a location breakdown structure (Janssen, 2014).

A location breakdown structure is typically based on the spatial properties of the finished product, i.e., a building with apartments or offices, and is therefore of limited use during the construction process. In the ASHVIN project the location breakdown and structure is based on the locations defined in the construction process, such as locations (e.g., spaces) for workers, material, logistics, equipment, etc.

Akinci et al. (2000) provides with a space taxonomy that can be applied to describe and manage different types of locations at a given point in time, see figure 10.

		Activity 1					
		Building Component	*Work space*	*Equipment Space*	*Hazard Space*	*Protected Space*	*Temporary Structure Space*
Activity 2	*Building Component*	**Design Conflict**	**Congestion**	**Congestion**	**No Impact**	**No Impact**	**Severe Congestion**
	Work Space		**Congestion**	**Congestion**	**Safety Hazard**	**Damage Conflict**	**Congestion**
	Equipment Space			**Severe Congestion**	**Safety Hazard**	**Damage Conflict**	**Congestion**
	Hazard Space				**No Impact**	**Damage Conflict**	**No Impact**
	Protected Space					**No Impact**	**Damage**
	Temporary Structure Space						**Severe Congestion**

Figure 10: Space taxonomy (Akinci et al., 2000).

2.7 Master schedule

A master schedule represents a summary-level project schedule for the purpose of identifying all major deliverables and milestones for the project, including components in the individual work breakdown structure (Project Management Institute, 2021). Master scheduling is the overall umbrella that facilitates the detailed planning process that tracks manufacturing output and can be applied to any managerial procedure.

2.8 Lookahead schedule

The customary approach is to prepare a master schedule that is used as a basis for plans of more specific nature, like more detailed short-term plans, such as phase schedules and six week look-ahead schedules (Koskela L. , 1999). These schedules are in many cases discipline oriented and do not explicitly consider the spatial layout of a project nor the spatial interaction between construction trades. Typical problems that arise as results of this planning practice are sub-optimization, out-of-sequence work and inefficient work- and space buffers. The updating of the master schedule is usually deficient, and consequently task management, at the short term, is largely done informally by the foremen or left to the teams on site to be taken care of by mutual adjustment (Koskela L. , Management of Production in Construction: A Theoretical View, 1999). As a result, the macro-management of workflow, which concerns the management of the flow of resources through locations in projects, is often left to ad hoc management on site where there is little opportunity to change construction execution strategies.

2.9 Last Planner® System of Production Control (Last Planner).

The process method is based on a combination of different methods. The overall methods are based on last planner methodology, which promotes flow and resource optimisation.

The term “last planner” refers to the people on the team responsible for making the final assignment of work to specific performers and ensuring they have the materials, equipment, and information available to complete their assignments. During the design phase, last planners are typically architectural and engineering project managers. During the construction phase, last planners are typically foremen and superintendents for the trade contractor crews (Richert, 2017).

The Last Planner System is organised in five parts according to the following figure, see figure 11.

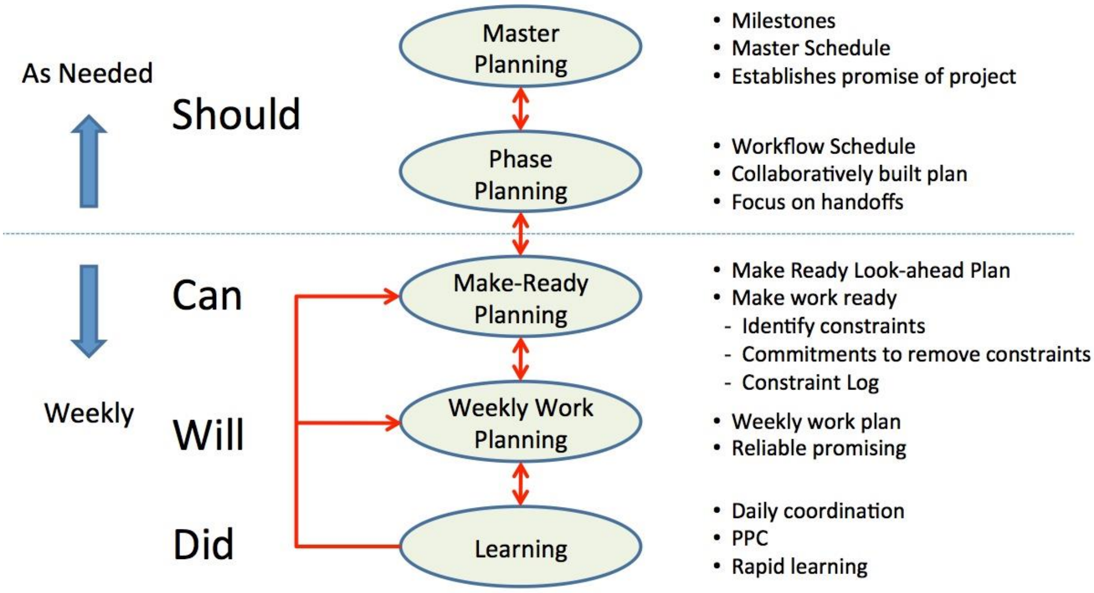


Figure 11: Last Planner System (Richert, 2017).

2.10 Prerequisites for a construction task

In order to make work ready, i.e., can a task be executed, as described in the figure above, a number of prerequisites for a task must be planned for and must be controlled, as outlined in the following figure.

These prerequisites have a spatial and temporal dimension. Koskela (1999), identifies space a prerequisite, but space itself can be defined in different subcategories, based on the work by Akinci as included in the above. Hence, a complex and myriad network of spaces that are temporally allocated for different task perquisites emerges. Each one that must be managed. Proper task and space management add greatly to efficiency and safety in construction, see figure 12.

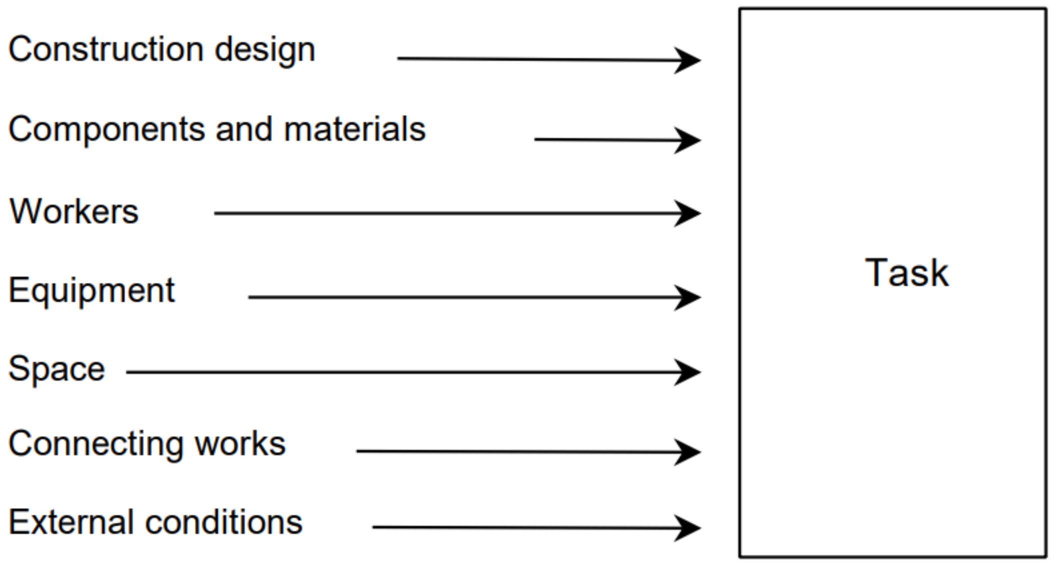


Figure 12: Prerequisites for a task (Koskela, 1999).

2.11 4D CAD

4D CAD models are typically created by linking building components from digital twin models with activities that are scheduled for the construction process. The construction schedule(s) can be simulated and analysed, based on real-time data. 4D CAD is an efficient visual tool to create a common understanding of the schedule logic. Opportunities can be found for more effective utilization of the site. In addition, potential safety hazards can be detected.

Typical 4D CAD models do not include locations for the construction process as described in the above but are limited to building components and possibly spaces such as rooms and corridors. Current 4D CAD models are of limited use for micromanagement of construction tasks.

2.12 Location-based scheduling

The location-based scheduling is a visual scheduling technique that allows the planner to explicitly account for flow of a project. The method is well-established within the lean construction community. A typical example is the line-of-balance scheduling method. Schedules are created by lines in diagrams to represent different types of work performed by various construction crews on specific locations (Jongeling & Olofsson, 2006), see figure 13.

By combining location-based scheduling with 4D CAD one can gain insight in both the flow on construction tasks, but also in the spatial logic. The spatial logic of construction sites is in many cases more complex and intertwined than a location-based schedule, such as a line-of-balance diagram may suggest. Hence, the two methods complement each other since they provide insights in each other that they would have been lacking on their own (Jongeling & Olofsson, 2006).

1. Same activity in several locations at the same time	- Continuing tasks of equal duration
2. Crossing of activities	- Standard production rate
3. No time and space buffer	- Activities have time and space buffers
4. Several activities start at the same day	- Slacks at start- and end time
5. and 6. inefficient use of time	- Work divided equally over construction time

Figure 13: Examples of Line-of-Balance diagrams. Locations are represented on the Y-axis and project time on the X-axis (Jongeling & Olofsson, 2007).

2.13 Digital solutions for control with the help of Digital Twins

There are innumerable ways to control a construction project by using digital twin data, it all depends on what digital tools one has available and what data one wants to collect.

In several whitepapers from authors Sezer & Rudberg (2020, 2021a, 2021b) examples are provided on how digital tools can be used to monitor construction sites. One example Sezer & Rudberg (2021a) give, (Rudberg & Sezer, 2020)￼. By using an AI system supported by cameras and automatic visual object recognition it is possible to create digital geofencing that helps crane drivers in their work (Rudberg & Sezer, 2020).

A third example is using a system with Bluetooth beacons and SmartHelmets to locate, identify and prevent accidents on site (Sezer & Rudberg, 2021b). A SmartHelmet is an Internet of Things (IoT) device that collects and syncs data to a digital twin. The device detects when there is a fall or a hit and sends a warning signal to site management and can, together with Bluetooth beacons, both locate and collect information considering the affected worker (Sezer & Rudberg, 2021b).

A last example is Qlocx, which is a delivery container with one to two doors with digital locks, which makes it possible for drivers with deliveries to open the container through an app and deliver the goods safely without having to contact staff on site (Qlocx, n.d.). The Qlocx solution was used in Demo 5 Gothenburg.

3 METHODS

The work conducted in task 4.3 was divided into three steps. The initial step was to create a process model customised to the various digital tools used on the demo-sites with the ISO 21500:2012 standard as a foundation.

The second step was to discuss with the three demo-sites which data-collection methods had been used and how the collected data corresponded to the predefined KPIs.

The third and last step was to analyse the information from each demo-site and draw conclusions on how well the process model could be applied to each case.

3.1 Creating a process model

To generate the process model, the initial step was to identify what different phases a project generally has during construction. The second step was to decide a few tools that could be used during these phases.

The phases together with the tools were thereafter used to create a grid where the process model could be applied. The phases constituted columns while the tools were the horizontal swim lanes (see figure 14). Thereafter, activities and documents for each phase were identified.

	INITIATING	PLANNING	IMPLEMENTING	CONTROLLING	CLOSING
1. SCHEDULE					
2. 3D-MODEL					
3. 4D-MODEL					
4. CONSTUCTION SITE INPUT (COLLECTED BY DEMO TOOLS)					
5. DATA ANALYSIS					

Figure 14: Table representing the foundation for the process model.

3.2 Connecting process model to demo-sites

To test the process model, it was compared to how work was conducted on the three demo-sites and more specifically to what data-collection methods they had used. This way it was possible to determine to what extent each demo-site had collected data considering the KPIs they had decided to investigate in deliverable D4.1 *A set of KPIs to plan and monitor productive, resource efficient and safe construction sites*.

It is deemed suitable however, for the described purpose to apply the process model to a conceptual, fictive, and general floorplan, i.e., not related to any demo site or other construction. The reason for creating a simulated environment is to ensure generalization. Also, all methods of collecting data can be analysed based on the same basis. The goal here is not to create a real-life simulation but just present an example of how this method could be carried out.

3.3 Analysing process model and suggesting improvements

Finally, the gathered information from the demo-sites was analysed and compared to the process model to see what improvements could be done to the model for an improved application.

4 RESULTS AND ANALYSIS

4.1 Result for process model

The produced process model contains five different process groups: initiating, planning, implementing, controlling, and closing and is supposed to be applicable on demonstration sites within the ASHVIN project (see figure 15). One purpose of this report was to support risk management in the construction sector with the help of a process. The risk management angle in this scenario is assumed to be calculated into the process as a result of proceeding in the activities and make use of the process in action. The aim of using such a tool or process is to foresee and handle upcoming issues before they are a bigger issue then they needed to be, this is how risk management is taken into consideration in this report.

The process model is read column by column. For each process group the activities for the digital tools are conducted simultaneously. The arrows show the workflow and how the different activities contribute to the next upcoming activity.

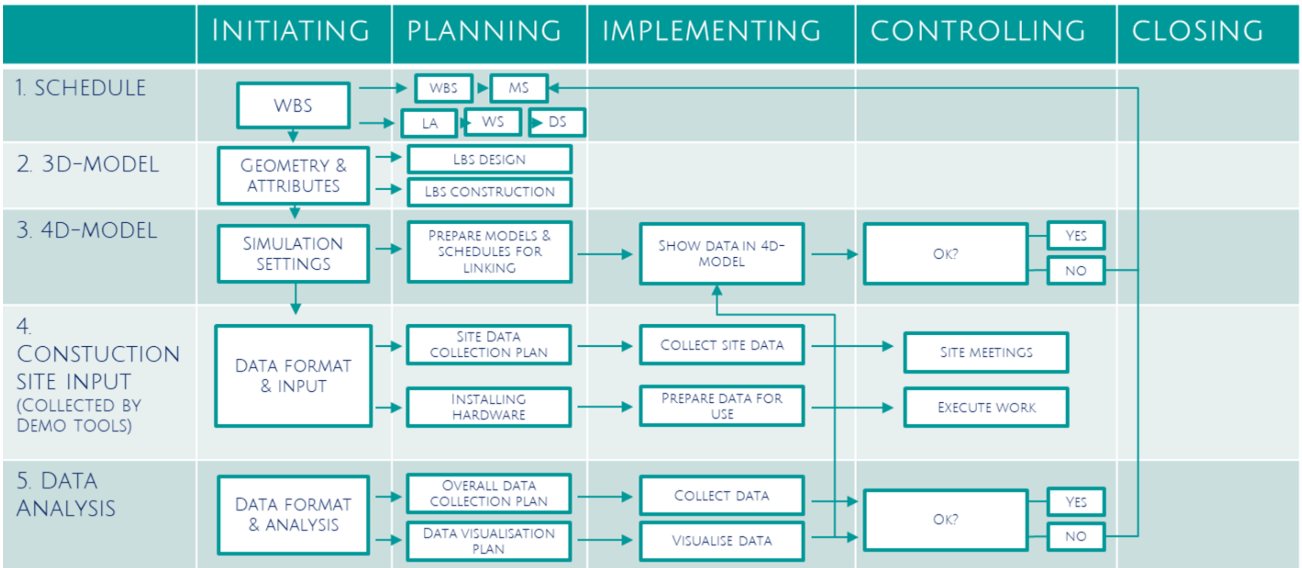


Figure 15: Produced process model.

4.1.1 Process groups

In this section the process groups are described so that the process model is applicable to any construction project which aims to utilise data from the site to support planning.

Initiating: To initiate a project, it is crucial to determine what ambitions there are within the project and what granularity the process model should have. This decides what key performance indicators (KPI) should be used and which analysis methods should be used later to make data analyses, this has been discussed earlier in the ASHVIN project during Deliverable 4.1. It is also important during this phase to define tools to plan and control the specific construction project.

Planning: The planning phase is crucial for successfully and effectively plan and control the project. In this process group the project is planned in detail with multiple activities that produce various documents to be used in later process groups. The planning processes are used to conduct detail planning and the granularity of the planning should be adjusted according to the project's need of guidance and performance measurement. The tool DES, created in the Ashvin project would be tool to use in this case.

Implementing: During the implementing phase site data is collected. The data can be used during the next phase to control the project in various ways.

Controlling: It is essential to the project to use the collected data from the project during this phase to control its' activities. By reviewing collected data, it is possible to decide whether plans for the project needs to be altered or not. When data is reviewed it is possible to create a feedback-loop from this phase back to the planning phase to make planning changes as needed. The controlling stage is of particular importance for the risk management regarding, process efficiency, safety, and resource use.

Closing: During this phase the project is formally coming to an end and knowledge from the project is studied for use in future projects. Since this phase is not in the scope of the task, it will not be investigated and developed in the model.

4.1.2 Schedule

Initiating

Here, the level of detail is determined for the schedule of the individual project. Parameters that decide level of granularity is for example type of construction project, budget, and earlier experiences with planning. The granularity affects the sequent produced schedules in the project.

At this early-stage prerequisites for upcoming activities within the next stage of the process model are established. KPIs, analysis methods and level of granularity of the process model are defined.

Planning

In this activity, a **work breakdown structure** (WBS) for the project is created. The structure is thereafter used to create multiple more detailed schedules: a construction master schedule, a construction three week look ahead schedule, a weekly schedule and lastly a daily schedule for the construction work on site.

MS

The work breakdown structure constitutes the foundation, of which a **master schedule** (MS) can be produced from. A master schedule is a document which contains more detailed planning processes for the construction project, such as pre-design phase, design phase, construction phase and closeout phase.

LA

A **lookahead schedule** (LA) is created from the master schedule to make a more detailed plan for work ahead. A typical application of a lookahead schedule is to coordinate activities on the construction site for contractors for a shorter duration of time for example three weeks. This lookahead schedule is a function integrated in the DES tool fabricated within the Ashvin project.

WS

Based on the lookahead schedule a **weekly schedule** (WS) can be created to plan weekly work activities for the construction project. Lastly, daily schedules can be created. The DES tool could be the tool to use in this case similar to the lookahead schedule.

DS

The **daily schedule** (DS) is based on the WS and is where the breakdown of activities is broken down to a daily basis on the construction site. This allows the planner to determine what activities should take place each day and this is the schedule that must be the most customizable. Based on unexpected events this schedule needs to be able to adapt promptly. Like the lookahead and weekly schedule, the daily schedule would be integrated in the DES tool.

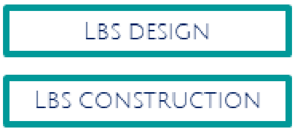
4.1.3 3D-model

Initiating

GEOMETRY & ATTRIBUTES

This activity is crucial to determine characteristics of the digital twin models to be used in the project. Geometry for both the design and construction models need to be determined as specific components and/or spaces. The type of information that is given to components within the model needs to be decided, for example information about doors, windows et cetera. In the same way, information for spaces needs to be decided which marks out areas within model with information considering what spaces will be used for.

Planning



For both the design model and the construction model a **location breakdown structure** (LBS) needs to be created and thereafter the actual BIM-models can be created.

4.1.4 4D-Model

Initiating

To be able to create the 4D model, multiple visualisation settings need to be defined, such as viewpoints, colour, and transparency settings. Other aspects to defined are what should be simulated and with what time intervals. This is further defined in T4.5 within the Ashvin project.

Planning

At this stage the digital twin models and schedules are prepared for linking. Thereafter components and spaces are linked to activities in the schedule which makes it possible to track progress. It is also here visualisation of different types of activities are fully determined. Linking is facilitated considerably by applying a common coding schema for locations and tasks.

Implementing

In this phase linking between digital twin models and schedules are finished, and information is available to be shown directly in the model considering the project.

Controlling

The data shown in the model can at this stage be controlled whether it is up to standards. If something is incorrect a feedback loop is created back to the initial master schedule to adjust.

4.1.5 Construction site input

Initiating

This section presents what type of data sources will be monitored and the locations on the construction site are determined. In addition, it is established what data format that should be used and with what time intervals data should be collected.

Planning

SITE DATA COLLECTION PLAN

INSTALLING HARDWARE

Based on schedules that have been produced in earlier stages, a site data collection plan is created. Thereafter hardware on site for data collection can be installed. What type of hardware to be installed depends on what type of data is of interest within the project.

Implementing

COLLECT SITE DATA

PREPARE DATA FOR USE

Data is collected on the site with different types of methods chosen by the project management and other active parties at the site. This data is then prepared to be analysed and used in the following steps. The relevant data is then used in each step of the process they are related to.

Controlling

SITE MEETINGS

Site meetings are conducted periodically during the construction process, these meetings are to coordinate and discuss the data that was collected during the previous step and to act if anything needs to be changed.

EXECUTE WORK

After these meetings and discussions, actions will be to handle any issues that have been brought to light from the data collections. This is the step called execute work.

4.1.6 Data analysis

Initiating

DATA FORMAT & ANALYSIS

When data is collected it must be analysed. In this stage the team must decide on how they want to present the data, and what information they want to gain from the dataset. It is first when the team has decided what they want to gain and collect from the site, that they can analyse the formatted data. The DES tool could be a utensil to analyse some is data, depending on what type of data the person is interested in. For a more detailed version of what Data the DES tool could analyse, see D4.7 in the Ashvin project.

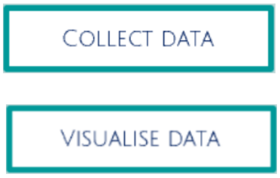
Planning

OVERALL DATA COLLECTION PLAN

DATA VISUALISATION PLAN

An overall data collection plan and data visualisation plan is created. The data collection plan decides what data should be collected and how it will be collected while the visualisation plan decides how collected data will be visualised to be understood in a simpler manner. This process could be related to T4.5 in the Ashvin project and the work done regarding how to develop management process and illustrate it. Furthermore, this is a visualisation that should then be able to illustrate in the DES tool.

Implementing



Based on the plan and other decisions taken in the earlier step the data is collected from the site. This collection of data is then processed and visualised to display a more coherent set of data, more relevant for the team.

Controlling

Processed and visualised data is examined, and it is decided whether it is satisfactory or not. If not, a feedback loop is created back to the master schedule in order to make adjustments.

4.2 Results for methods used on demonstration sites

In this section, collected information considering data-collection methods is presented for each demonstration site. The sites and the information presented beneath are tools that have been used at the different demo sites. It is these tools that have been taken into consideration when the process presented in figure 15 has been developed.

4.2.1 Barcelona

Table 1. Productivity PI:s for demonstration site Barcelona

Productivity	
PI:s	**Barcelona**
Percentage of plan complete	*Accelerator* - to check off when for example columns have been vibrated.
Non-Productive working time of professionals	Sensing box for motion tracking of cranes – Sensors that track motion, through which you can gather information regarding time of use.
Component's properties	*Laser scanners* – to scan areas and extract the 3d point clouds *Sensor* – to measure temperature *Sensors connected to an app* – that measure moisture and temperature of concrete. *Accelerometer* – To gain information that each concrete column is vibrated the same amount.
Productivity rate	*Accelerometer* – You can see when a column was vibrated, that allows us to see how well the casting of columns proceed. *Multi-sensor device detecting acceleration, angular velocity, and GPS position* – Allows to

	know the speed and altitude of the crane, with this data a productivity rate can be drawn.

Productivity was measured with multiple digital tools at the Barcelona demonstration site and is presented in Table 1. The combination of input from the tools provides an overview of how work was conducted and made it possible to monitor the productivity. Production of columns was the only building component that was monitored at this site. In addition to columns, information about usage and movement of the construction crane and concrete properties were collected.

Table 2. Resource efficiency PI:s for demonstration site Barcelona

Resource efficiency	
PI:S	**Barcelona**
Waste factor	*Accelerometer* – The accelerator will be able to find the optimal amount of vibrating the concrete will need. By having a set amount of vibration and knowing when you finished will save time and energy used.
Number of concurrent trades on site	N.A.
Percentage of available space used	*Videos* – taken from drones and cameras, shows how the area is used.
Utilization rate of equipment	*Multi-sensor device detecting acceleration, angular velocity, and GPS position* – By knowing the position and speed of the crane, the sensor will be able to deduct how well the crane is being utilised on site.

Table 2 shows how resource efficiency was measured with various digital tools at the Barcelona demonstration site. The data collection methods made it possible to see how resources were used such as energy for producing columns with concrete, how the spaces at the construction site were used and how the construction crane was utilised.

Table 3. Safety PI:s for demonstration site Barcelona

Safety	
PI:S	**Barcelona**
Number of reported issues related to the accidents on construction sites	N.A.
Safety factor	*Drone* – With its overview of the site, it will show areas that are not restricted correctly and other safety hazards. The drone is driven by a person on site and collected data analysed manually.
Strength of structural components	*Accelerometer* – Will show if a concrete structure was not vibrated enough when casting. The device is attached to the mould manually.

Measuring PI:s in conjunction with safety was not in focus for the Barcelona demonstration site however, digital tools such as drone and accelerometers could have been used for that purpose, see Table 3.

Table 4. Cost PI:s for demonstration site Barcelona

Cost	
PI:S	**Barcelona**
Cost of equipment and workers	*Accelerometer* – Will show the right amount of time a casting of concrete will need to be vibrated. This will save time when casting which will lower the costs. *Crane Sensor* – Can give information how often a crane is being utilised and by that how much the crane needs to be used.

4.2.2 Rinteln

Table 5. Productivity PI:s for demonstration site Rinteln

Productivity	
PI:s	**Rinteln**
Percentage of plan complete	*Web-camera* – will give the visual information regarding how much of a plan has been completed.
Non-Productive working time of professionals	*Web-camera* – and its collection of videos will be able to show through videos how much non-productive time that takes place in a certain spot.
Component's properties	N/A.
Productivity rate	*Web-camera* – gives a good visual notice of how the productivity is going. You will be able to see where you were at the start of the day and where you're at in the evening. *360 cameras* – like web-cameras will collect information regarding where the site is at that time the camera was taking the video or footage. That can then be compared with later versions of videos and photos taken at the same spot at later times. *Drone* – if drones are used in an interval, they will, similar to the web-camera and 360 camera, give a good visualisation of how the site has been developed during that interval.

At the Rinteln demonstration site, both web-camera and drone were used to measure productivity, see Table 5. The web-camera was connected to a website which made it possible to check the progress at the demonstration site with a 10-minute interval. 360 cameras and a drone were also used to collect video and image material at the site to see the progress that was made.

Table 6. Resource efficiency PI:s for demonstration site Rinteln

Resource efficiency	
PI:S	**Rinteln**
Waste factor	N.A.
Number of concurrent trades on site	N.A.

Percentage of available space used	N.A.
Utilisation rate of equipment	*Web-camera* – equipment that is shown in the visual range from web-cameras, will be able to show how often and for how long they are used. *Drone* – drones will in a similar way to the web-camera show how often larger equipment is used on the site.

Resource efficiency was not a PI in focus at the demonstration site, and the only PI that was considered was utilisation rate of equipment. The tools mentioned here might be able to contribute to the utilisation rate of equipment, but it was not planned to do so. For this to work it means that someone needs to look through the visual data and conclude how often a tool is used and at what rate.

4.2.3 Gothenburg Sweden, Kineum

Table 7. Productivity PI:s for demonstration site Kineum.

Productivity	
PI:s	**Kineum**
Percentage of plan complete	*Scanning robot*[1] – In a set interval allow the robot to walk around and scan the progress of the site. This will allow project members to check of the percentage of the plan that is completed.
Non-Productive working time of professionals	N.A.
Component's properties	N.A.
Productivity rate	Temperature data was used to control cooling and heating (energy efficiency) but also to plan activities (for example, RH and temp to know when floor covering at different floors were possible due to indoor climate. Container with digital lock was used on site to receive deliveries safely and effectively.

For the Kineum demonstration site, a scanning robot (Spot robot) equipped with a laser scanner was able to make several screenings on certain building floors in order to track work progress, see Table 7. The progress could be identified by comparing the collected data with the BIM model of the project and project schedules. A digital tool

[1] An autonomously adaptive robot, developed and produced by Boson Dynamics, with a clear resemblance to a dog

that aims to do this is currently developed within the ASHVIN project and called 4DV-C. Furthermore, the same data could be used to determine the spatial locations of different components also ensuring that possible errors could be detected early which led to decreased cost (less work) and time.

Table 8. Resource efficiency PI:s for demonstration site Kineum

Resource efficiency	
PI:S	**Kineum**
Waste factor	
Number of concurrent trades on site	The sensor system included tracking activity (motion activity) in the measurement area. Due to privacy issues, no camera could be used for tracking.
Percentage of available space used	N.A.
Utilization rate of equipment	N.A.

The demonstration has had high ambitions to monitor and control waste on the construction site but did not use any digital tools in the process. The waste was collected in bins on each building floor which then were emptied in a larger container each evening by a dedicated waste subcontractor. The waste content is visually controlled by personnel on site and divided into the fractions of wood, metal, gypsum, mineral wool, concrete, plastic, and hazardous waste. Additional inspection was carried out by the waste management company and the project was burdened by additional costs if the waste had been sorted incorrectly. However, this company also provided images of the results that was used by NCC to improve the waste sorting process on site. Currently, 81% of the waste has been sorted, well exceeding the requirement of 70%.

In conjunction with construction work, waste accumulation was carried out continuously. The waste is both taking up space at the construction site which can hinder construction to proceed and is also an environmental challenge. Since waste can consist of different kinds of materials, it is important to divide it into different categories so it can be managed and possibly recycled in correct ways. This can ultimately contribute to a better use of natural resources.

Table 9. Safety PI:s for demonstration site Kineum

Safety	
PI:S	**Kineum**
Number of reported issues related to the accidents on construction sites	App reporting of accidents or incidents – An app has been used at the demo site, allowing project members to report accidents, incidents and other inquires when needed. This gives a good overview of the number of reported issues at the site.
Safety factor	App reporting of accidents – will as well here give a good overview of what activities might be at a higher risk of accident.
Strength of structural components	N.A.

Reporting of accidents and safety issues on site was made through an app, see

Table 9. After every report and investigation was conducted, and one of the initial methods used was Root Cause Analysis. All personnel of site were encouraged to report issues, but it was mainly the foremen's task. Another app was connected to sensors on site to send warning notifications to personnel on site when dust and noise levels exceeded certain levels. The same app was used in case of emergency on site, by connecting emergency equipment such as warning lights and alarms to the sensors.

The connection between these tools and the process presented earlier in the report. Is to represent some tools that could be used to acquire data in the process. The process seen in figure 15 is depending on data that are acting as inputs in the process. This section represents the tools that have been encountered in this study and that have been used on the demo sites. This does not mean that the process presented only function with these tools exclusively, but they are considered to give a good basis of what the process could be used for.

4.3 Analysis for methods used on demo-sites

As described above, based on the methods that have been used at the selected demo sites, an analysis was conducted. This analysis was based on how the methods mentioned can attribute to the two Break Down structures.

4.3.1 Collecting data and its contribution to LBS

For construction activities to be conducted, certain prerequisites need to be fulfilled. Space and resources for each activity need to be in place to create the desired workflow which the lean construction concept strives for. To facilitate and ensure that the desired prerequisites are available, digital tools can be used to monitor a construction site in various ways and is presented below.

- *360 Cameras*
  The 360 camera is placed in selected positions scattered around the site. When this location is known then the 360 cameras could act as an attribute when reviewing the construction site regarding to LBS. The camera can also be worn by a worker or foreman while they are on site.

- *Sensor-Metrics for external influences*
  Sensors that measure external temperatures, particles, noise pollution, humidity and movement and are placed in known location spots like the 360 cameras. They will give an understanding of how the construction site is experienced at any given moment. With the assistance from the LBS, it is possible to get an understanding of where in the site the values are measured.

- *Laser scanner*

The laser scanner will be a more mobile tool allowing the scanning to take place where it is desired. Scanning can create a great overview of the development by creating point clouds which can be compared to the BIM model of the project. If a scanning is done in set of intervals and it is connected to the LBS then a very well detailed understanding of the progress will be retrieved based on location.

- *Scanning robot*

The scanning robot is similar to the laser scanner, but it is able to walk around by itself. The scanning robot understands where it is located at any moment with the help of a model, and it can go around and collect data connected to the LBS.

- *Fixed web camera*
  The web camera is like the 360 cameras placed in selected locations in the construction site and it will be limited to that area. However, it will give a good understanding how the process is advancing in that space with the help of videos timelapses. If these cameras are connected to the LBS a good understanding can then be retrieved about how that specific location is developing. Possible camera positions could be in scaffolding, cranes or other places that are situated relatively high above the ground, enabling an overview of a specific part of the construction site.

4.3.2 Collecting data and its contribution to the WBS

How could tools attribute to the WBS process? This provides insight in what work is done.

- 360 cameras
  The 360 camera could be connected to the WBS due to its collection of visual data. When the camera is set to a certain spot, and it takes in visual data on a set basis, it will be able to show the progress of activities. If implemented in this manner, connection to the WBS could be made where a clear visual progress could be retained.

- Accelerometer
  The function to instantly know if a concrete column or any other concrete fixtures has been cast, could then be connected to the WBS. This data is also compared to previous casting to give a good indication of how the casting should progress. It could via the WBS that has the progress mapped, check of steps as the casting is progressing, showing a clear development of the casting activity.

- App-reporting of accidents
  An app that is collecting the accidents reports and collecting data regarding what activities that are prone to a higher risk of accidents could be connected to the WBS. Meaning that activities in the WBS might be able to have a safety rating of some sort and by that be able to advise workers and planners to be more careful during those activities.

- Sensor-Metrics of external influences
  The construction site has a lot of external influences such as temperature, moisture, weather etc. These external factors might influence how and when certain activities can be conducted on the site. When creating a WBS of activities, you will have to keep in mind these external influences and plan accordingly. If during the WBS planning, the planner will add in the prerequisites that certain activities need and connect this to the sensors. Then the sensor will be able to detect when the optimal time is to conduct the activity.

The tool DES could be a tool used to present the data collected in such sensor metrics. For example, with a floorplan of a level and showing heatmaps of temperature, wind and so on.

- Crane sensor
  The crane sensor and its function to record how long an activity takes, and at what speed. Should be able to be connected to the WBS and collect data regarding how long some activities will take and when they really took place. Similar to the accelerator, the crane sensor will be able to check of steps in the WBS as the activities are progressing and compare it to previous lifts.

- Drone
  The drone has a good overview at the construction site. Similar to other cameras it will be able to collect visual data from the site on a regular basis. Regarding activities that can be seen from the drone, these could then be connected to the WBS and checked off as the activities are progressing.

- Laser scanner
  A laser scanner can be placed on site and scan the area around it. Similarly, to cameras, the laser scanner creates point clouds which makes a visual understanding of the progress in that area and if it is connected to the WBS it can then check off activities as they are advancing.

- Scanning robot
  The scanning robot has the ability to walk around the site by itself on a timed schedule and collect data on a regular basis. Resembling to the other types of scanning and cameras mentioned, the scanning robot will be able to generate 3D point clouds and by its connection to WBS be able to check off activities as the project advances.

- Web camera
  The visual data collected by web cameras can be connected and used in the WBS much the same as other visual collecting methods could be used. The visual data is collected and can then be analysed based on the WBS and checked off as the activities are progressing.

4.3.3 Process model and collection of data

A simulation regarding these mentioned methods of collecting data in a combination with the process model presented earlier in this report is outlined below.

In this analysis we assume that a WBS and a MS has been created and is reinforced in the project and site. These two will act as the framework for the analysis and the methods will accommodate and be compared to these three structures and schedules.

The MS and WBS together will allow the project to then create a LA, WS and DS. These schedules will be more adaptable to change and be modified based on the data collected from the site in later stages

The next step for the team is to conduct a Geometry and Attributes analysis and section of areas, rooms, and components and label them with the needed information. This step is crucial to be able to create the LBS plan for both Design and Construction.

We can now assume that all the other preparations that need to be done before the team is able to collect data has been implemented, figure 16.

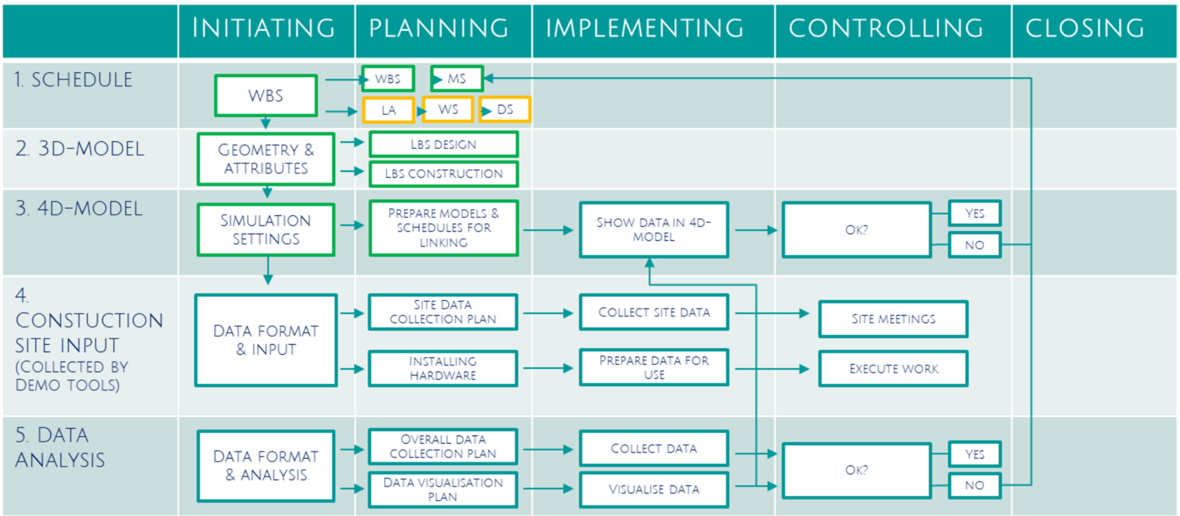


Figure 16: Process model with emphasised activities in the initiating and planning phases.

Based on the figure 16 we can now see that we have the schedules needed to start production, we have set the geometric and attributes with names and the information needed to create the LBS and we have now set a 4D-model simulation linked to the schedules.

The next step is now to focus on step 4. Which is Construction Site Input. The first column here is to set on Data Format & Input. This is where it is time to decide what data we want to collect and how. In this case we want to make use of all the methods mentioned in 4.3.1 and 4.3.2, see the table below for the breakdown.

A tool is broken down into columns.

- Data type – what type of data is collected with this tool? Is it numeric and can be presented in a table or graph or is it a visual data such as a video.
- Where – Where on the site could the tool be used to gain relevant data?
- When – When could this tool be used on site to gain relevant data?

Table 10: Map of tools and their characteristics.

	Data type	**Where**	**When**
360 cameras	Visual	Mobile with worker or foreman	Sporadically when time suits

Accelerometer	Numeric data	Placed when casting	When needed
App - reporting of accidents	Numeric data, manual recordings of data	Ubiquitous	Used when incidents occur
Sensor - external influence	Numerical data	Placed on strategic places around the site	Continuous measurements
Crane sensor	Numerical data	On crane	Continuous measurements
Drone	Visual data	Aero visuals from outside	Weekly basis
Laser scanner	3D point clouds	Mobile with foreman, placed on selected spots	Weekly basis
Scanning robot	Visual data (photos) and 3D point clouds	Mobile, walks around selected levels	Weekly basis
Web camera	Visual data	Set places, selected by team	Daily basis (new picture every 10 min)

We assume at this stage that the Site as well as the Overall Data Collection plan has been planned and is now ready to be implemented. The Installation of Hardware and Data Visualisation plan has as well been installed and created ready to be implemented on the site. The next step is then to collect data and analyse it, see figure 17.

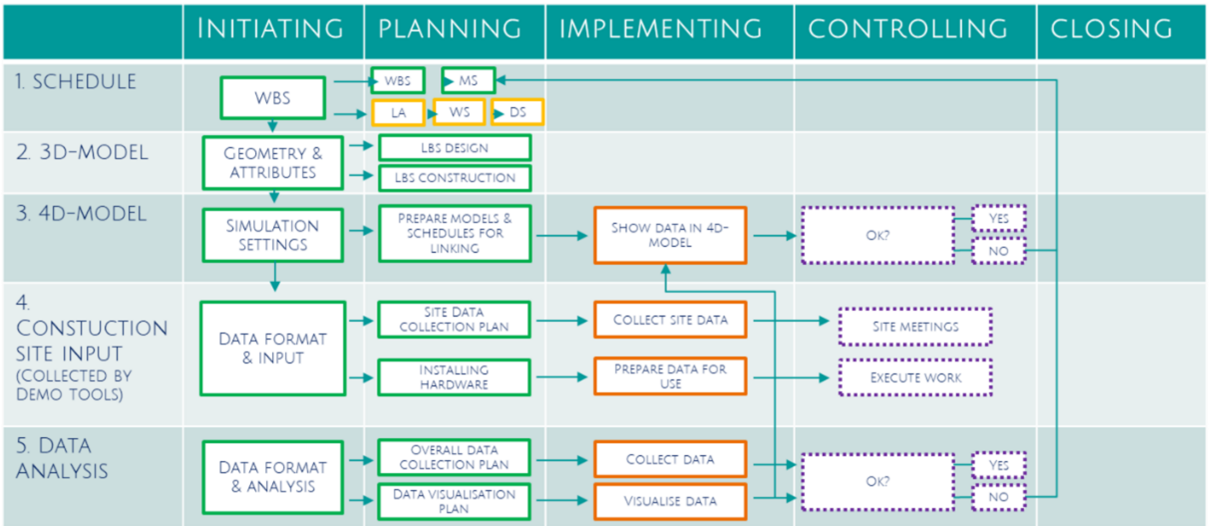


Figure 17: The process model applied to the analysis of the different ways to collect methods.

360 Camera

The first method of collecting data is the 360 cameras. A foreman walks out on site and places the camera in a spot. The 360 camera collects visual data that can then be seen through computers or VR headsets. It gives a complete spherical visualisation of the site, and it allows the foreman to compare earlier data collections with the new ones as well as with the 4D model. The foreman takes this information to the rest of the team and together they decide if it looks accurate to the plan and schedule.

This could as well be used with the help of the Demo tools presented in the Ashvin project. If the data looks accurate to the plan, then the schedule continues as planned. If the team realises that the data, they have collected shows that less or more has been done compared to the schedule then they will have to go back to the schedules and adjust it accordingly.

Accelerometers

It is time for casting a number of concrete columns. The team has decided to use an accelerator tool to measure how long each column is vibrated for. They first test the concrete batch and decide on a time interval that is optimal to vibrate for and sets the accelerometer up for this interval.

The accelerometer is fixed on the casting moulds side, visible to the workers. The concrete is filled up in the mould and the workers start the vibrations. When the vibrations have reached the set interval the accelerometer will signal this to the worker and the vibrations are switched off.

With the accelerometer the information is direct, and the adjustments happen concurrent with the activity. This means that no further readings of data or meetings will have to take place to use this method of collecting data.

This collected data collected could then as well be presented in the DES tool to check of productivity within the planned activity.

App-Reporting of incidents

An app is downloaded on all foremen’s’ and workers’ phones before construction commences at the site. The app allows everyone to comment and report on incidents and hazard warnings relevant to the site. Data collected on the app, will be connected to the incidents and hazards such as who was involved, what activity caused it, what was the consequences and reason for it happening. The Demo Site has as well collected data from earlier projects resulting in having an index of data and information from previous experiences how risk management should be taken into consideration. All this data could be very useful for foremen on site to get an understanding of what activities are at a higher risk and have more tendencies to be involved in incidents or hazards.

The app in question is not developed by actors in the Ashvin consortium but it is considered a tool that could add great value to the project and the process.

In this case connected to the process map, see figure 15. The data is collected continuously during the whole construction process when an incident or accident occurs. The new information collected in the app combined with earlier data should be reviewed frequently to recognise high risk activities as early as possible. The data can be visualised in graphs and tables showing relevant information needed by the foreman.

The next step for the team is to present the data in a meeting and discuss further actions to minimise the risk for more incidents regarding certain activities. Depending on what has caused the incidents and hazards, the team might decide on altering the schedules to address the higher risks. This could for example be to extend the period when an activity is supposed to take place or to move the activity to make sure that no other activities will take place in the same area of the site during the same time.

Sensor – External influences

The project team has decided on strategic places around the site where they have placed sensors collecting data regarding temperature, moisture, and other relevant information. The sensors collect this data and presents it to the team as a survey of the site showing the places where the sensors are placed and the data at that point. This gives the team a clear overview of the site's external influences and internal influences. Multiple sensors are placed around the site due to how the factors could vary from for example outside to inside and in different rooms. See figure 18 for example.

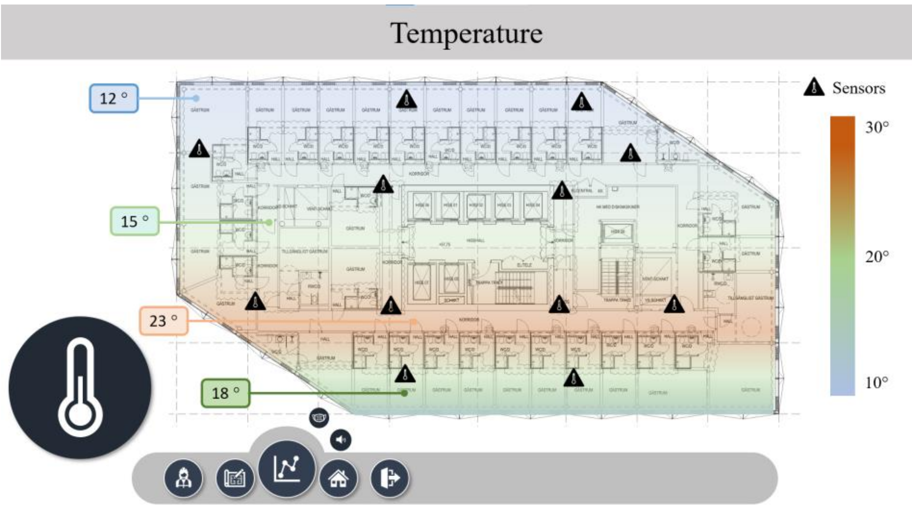


Figure 18: Visualisation of sensors stationed around site, (Göransson, 2022)

This type of data could be used for planning activities that are relying on certain prerequisites and that are on hold for the prerequisites to materialise. For example, the casting of concrete needs a certain temperature to be able to cure. The team can then place a sensor close or in the area where the casting will occur and monitor the temperature. When this temperature is reached the team will get a notification that it is optimal to cast the concrete and the activity can start.

When this is viewed from the process model in figure 15, the data is collected regularly, and the data is visualised for the team. When the data is collected and analysed the team will take decisions if the external influences allow them to conduct the activities planned in the near future or if they need to reschedule.

Crane sensor

The crane sensor is placed on the hook block at the end of the crane. It is collecting data during the times that the crane is in use at the site. It will give the foreman and the team information regarding how frequent the crane is utilised and how well.

This data presented with the DES tool will assist the team in understanding how long certain activities might take, such as lifting material from one spot to another or how long a prefab wall takes to install. After that the sensor has collected some data, the team will then be able to analyse the data and get a better understanding if the activity that they planned for will take as long as they assumed in the schedule.

If this is not the case, then the team will have to return to the schedule planning and maybe redesign the weekly and daily schedule to a more realistic timeline.

Drone

The team has decided that the drone will fly once every week to collect visual data of the site. The data collected with the drone is in a video or photograph format and it will allow the team to compare previous weeks data with the new. The team will be able to notice issues efficiently by having an overview of the site.

This can then be discussed with the team if issues are sought out and they might need to return to the scheduling planner to adjust the time schedule.

Laser scanner

The laser scanner is placed in set spots and collects data on a weekly basis. The laser scanner allows the team to collect data that can be compared to earlier screenings as well as the digital twin models. This allows the team to compare the scanning to where they were planned to be at that stage and adjust accordingly.

Scanning robot

Like the laser scanner, the scanning robot will walk around the site and generate 3D point clouds that can then be compared between model and schedule, preferably linked to the digital twin. This will allow the team to get an understanding of where they are in comparison to the timeline and by that could adjust it.

Web camera

The web camera is placed on selected spots across the site. The camera collects visual data on a set interval allowing the team to see the development as it goes. The team will with this method be able to collect data in a visual way and compare it to the schedule, preferably linked to the digital twin. They will be able to catch issues in an earlier stage and by that have the time and ability to adjust the schedule to a more realistic timeline.

End note

These methods in combination with the process model allows the team to detect issues, react and adjust the schedule to make the whole process smoother. It can assist them in planning when to take in certain disciplines and when to order materials. In that sense, these methods can contribute to the management of construction sites, in various ways.

It can lower the cost for the site by practising a more realistic timeline and to be able to adjust it accordingly as the progress of the site is ongoing. The site will not have material lying around for weeks to months waiting to be utilised and rooms will not have to be empty waiting for the next activity that could have taken place the same week but is planned the next month.

Some simulations have been composed to visualize these functions, one could be seen in earlier in the analysis regarding sensors and temperature, see figure 18. Another visualisation of how this process could be used is to plane activities and connect to a space layout of the site with information regarding how the development of the activity is going in comparison to the time schedule, see figure 19.

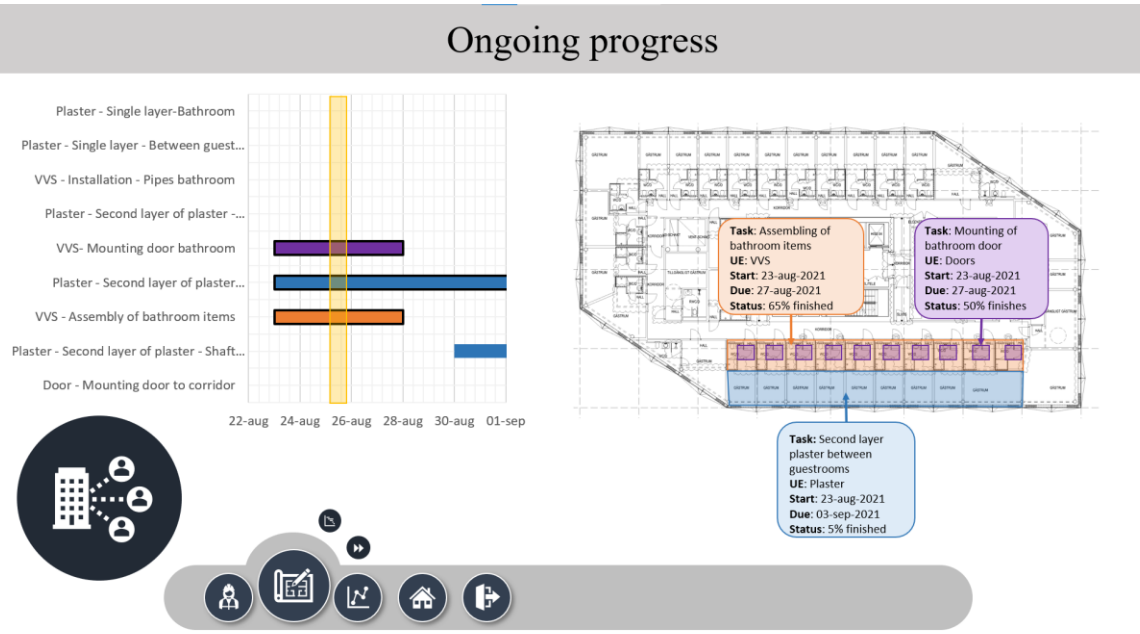


Figure 19: Visualisation of how a model/floorplan could be connected to a timeline and with the use of digital data see how the process is going, (Göransson, 2022).

The site will be more timed to perfection and each decision regarding the development will be more thought out.

The process model that has been developed and presented within this task could be further developed by taking more information in to consideration. In addition to the demonstration sites researched in this task, historical data from previous construction projects could be analysed in order to get more detailed insights in what construction activities that was more of less successful from various perspectives, such as cost, energy and safety. Another thing to consider is what sensors and digital tools are optimal to use to gather information to the process model. In this task just a few were used and, in a few ways, by researching other data collection methods the process model could possibly be altered in various ways.

5 DISCUSSION

5.1 Discussion

A large amount of video and image material was collected from the three demonstration sites that were investigated in this task. This material could have been used to analyse how safety work was conducted on each site.

However, due to privacy aspects, it was not possible to go in depth in the material and to analyse how individuals were conducting their work tasks. Even though the technology exists to monitor workers on site, privacy regulations make it challenging to do so. This argument was expressed from various project partners and is important to take into consideration when developing solutions to monitor work, both in regard to safety, but also productivity.

The work executed in this task has been strongly connected to the predefined KPI:s within the project by showing their connection to the process. It should be noted that the digital tools each of the demonstration sites have used can be creating value beyond collecting data specifically to the KPI: s. But it should be addressed that even though the tools that have been presented in this paper have assisted in creating the process model in the results, the process is not exclusive to specifically for these tools. Generally, sound implementation of relevant data collection can potentially lead to value creation, especially if the implementation process is able to provide real-time data to a digital twin model.

The process that is presented as the solution in this case is based on the Demo Sites of the project of Ashvin. The KPI.s and tools have both been large contributors for the reasoning and formatting of the process in discussion. It could be argued how well this process could be suited for an external project with maybe not the same budget for tools or the same time aspect. What is to say that this is a standardised process to use? This could be argued back and forth but the belief is that this process could act as the foundation of a more project-based process.

This result is mainly a theoretical result based on the information given by the demo sites. This process model is made specifically for the Ashvin project and the Demo sites active in this project. To suit a different project, it might be needed to be altered a bit to suit the specific projects and their conditions. There is great potential in applying these process methods in larger project, scaling up the implementation, supporting both the management process and potentially even the business process of construction projects.

5.2 Limitations

For most of the time period when Task 4.3 was conducted there were difficulties visiting and researching the demonstration sites, due to the COVID-19 pandemic. Various restrictions made it challenging for demo sites to try out the digital tools provided to collect data considering the multiple KPIs. This was due to covid restrictions, late deliveries and etcetera. This means that it has not been possible to validate the method in question in real life in combination with some of these tools mentioned in this paper. This has made it difficult to study whether the process model with its activities was suitable for the demonstration sites and what improvements could be made. Another challenge for the demonstration sites was that it was difficult to receive some of the sensors that were supposed to be used on the site, due to ordering issues and delays.

Other limitations that should be brought up are that this report only focuses on a few demo cases that has the access of time, budget, and tools necessary for the process to function at its optimal. This might not have been the case if other sites would have been used in the study.

6 CONCLUSION

6.1 Domain results

Multiple findings have been made throughout this study. Some of the more profound conclusions are presented below.

The main takeaway from the work within this task is how vital it is for a project to decide in an early stage the prerequisites that will be needed to control and affect the project during the construction phase. This is the reason why it is essential to make sure that the process model as well as the digital tools are applied in depth.

The second point to be made is to understand that all the KPI's mentioned in the results section can be collected using a multitude of different tools and methods. But to gain useful information from the collected data, a clear plan is needed on how to make use of the data that is collected and to make sure it is of satisfiable quality, preferably through real-time data implementation, linked to a digital twin model.

The tools that have been investigated in this study can be applied to a WBS and LBS to create an even more clear planning structure and overview of the site, leading to a more efficient construction site management process.

The produced and presented process model provides project teams with visual representations that make it easier for the various team members to understand, plan and control the construction process from an efficiency, resource use and safety perspective. The process model is based on principles from lean construction and effectively combines different data sources. The visual element of the process creates a common ground within the team to support their way through the model and the activities that come along.

The result of having a clear and simpler way to understand, plan and control the efficiency, resource use, and safety of the site is that the site has a more defined risk management system. By using a process such as the one proposed in this report the site would be assumed to have a more forward thinking of its activities. By incorporating assessment of the future into the process, it could then be assumed that the process of decisionmaking, and risk management would also be positively affected.

Both decision-making and risk management are two areas that demand consideration and an attentive approach from the individual making the decisions. requiring understanding of the conditions and limitations further down the line of a process. This is how it is believed that the process will result in a positive aspect in those areas.

Combing this process with digital twin data is where this process will thrive the most. The usage of collected data at a site and adding this to a digital twin, assures that the decision-making process has a good level of detail and relevant information to make sure that the decisions that are made on site are under the right conditions. The process supports lean project planning in the aspects of control and risk-management, and this believed this process is doing.

6.2 The Ashvin perspective

As given in the Grant Agreement (Annex I (part A), page 24), this report has addressed its main purpose of describing the business and decision-making processes to support lean project planning, control, and risk management with digital twin data.

6.3 Future studies

It would be interesting to be able to test the process model from the beginning of a construction project, in other words from the initiating phase. During this task the demonstration projects were already in the construction phase, which meant that it was mainly controlling activities that could be conducted according to the process model. Since the ASHVIN project was not a part of the planning phases for the demonstration sites it was not possible to test how the process model could be used for planning. By applying the process model earlier in the initial stage, it would be possible adjust the construction projects initiating and planning activities and get a more coherent overview during the later phases (implementing, controlling and closing). The ideal situation would be to create the feedback loop that the process model strives to create, from the controlling phase back to the planning phase and adjust the schedules according to the progress on site.

This might be able to happen due to that there is one year left of the project. Even though this paper is published it does not mean that the demo sites cannot still try to apply this process map at their sites.

Since the process model is a theoretical recommendation of how a construction project could be conducted, it would be relevant to further investigate how to implement it practically by letting various individuals use it in their daily work within all the construction phases. This way it would be possible to identify if the current model is lacking any activities or if some can be removed and if there are any structural alterations of the model that should be made. Is it easy to use and understand? Is there anything in the model that does not mirror the reality of construction work?

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