# D4.1 A SET OF KPIS TO PLAN AND MONITOR PRODUCTIVE, RESOURCE EFFICIENT, AND SAFE CONSTRUCTON SITES

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ASHVIN has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 958161. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

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| **Project Title** | Assistants for Healthy, Safe, and Productive Virtual Construction Design, Operation & Maintenance using a Digital Twin |
| **Project Acronym** | ASHVIN |
| **Grant Agreement No** | 958161 |
| **Instrument** | Research & Innovation Action |
| **Topic** | LC-EEB-08-2020 - Digital Building Twins |
| **Start Date of Project** | 1st October 2020 |
| **Duration of Project** | 36 Months |

| | |
|---|---|
| **Name of the deliverable** | A set of KPIs to plan and monitor productive, resource efficient, and safe construction sites |
| **Number of the deliverable** | D4.1 |
| **Related WP number and name** | WP 4 Control and real-time simulation of construction |
| **Related task number and name** | T4.1 KPIs for productive, resource efficient, and safe construction works |
| **Deliverable dissemination level** | PU |
| **Deliverable due date** | 30-09-2021 |
| **Deliverable submission date** | 30-09-2021 |
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| **Reviewer(s)** | Rolando Chacon (UPC), Lucian Ungureanu (TUB) |

## ABSTRACT

This document describes performance indicators that contribute to productivity, resource efficient, and safe construction works. Report also summaries the tools that will be developed within ASHVIN project and support tracking of progress of construction works. The most important tools and methodologies are: ASHVIN platform dashboards that provide a rich environment to consider and manage the performance indicators; Construction monitoring tool with productivity and safety KPI decision making dashboard (4DV-C); Privacy ensuring safety management, simulation, and training tool (SMT); A configuration management tool to track as-designed and as-built, as well as, to allow for seamless commissioning (CMT); Simulation-based real-time construction site and logistics planning tool (DES); Multi-physics model matching tool for status assessment of bridges and buildings (MATCHFEM); Lean project planning methodology. According to the interviews performed with managers of construction sites the number of times the site is getting organized and cleaned influences not only the safety of a site but also the productivity. In addition, the number of tasks that must be redone/corrected influences the morale of the workers and therefore the productivity of the work as well as the costs and the resources that are being used to finish up that task. ASHVIN project will support the calculation of following Performance Indicators: Percentage Plan Complete, Non-productive working time of professional, component properties, productivity rate, waste factor, number of concurrent trades on site, percentage of available space used, utilisation rate of equipment, number (and severity) of reported issues related to the accidents on construction site, safety factor, strength of structural components, cost of equipment and workers. Those indicators will be measured and checked on three ASHVIN demonstration projects: #4 Logistic hall construction in Germany, #5 Kineum office building in Sweden, #6 Office buildings in Spain.



## KEYWORDS

Key performance indicator, productivity, resource efficient, safe construction works

# REVISIONS

| Version | Submission date | Comments | Author |
|---|---|---|---|
| V0.1 | 20.06.2021 | Draft | Agnieszka Łukaszewska |
| V0.2 | 20.08.2021 | Comments from reviewers | Lucian Ungureanu |
| V0.3 | 23.09.2021 | Final document for coordinator | Agnieszka Łukaszewska |
| V1.0 | 30.09.2021 | Preparing for the submission | Lucian Ungureanu |

# DISCLAIMER

# ACRONYMS & DEFINITIONS

| | |
|---|---|
| API | Application programming interface |
| BIM | Building Information Modelling |
| CAD | Computer Aided Design |
| CDW | Construction and demolition wastes |
| DF | Data Fusion |
| DoA | Description of Action |
| DT | Digital twin |
| EU | European Union |
| FEM | Finite Element Method |
| GIS | Geographic information system |
| GHG | Greenhouse gas |
| GPS | Global Positioning System |
| IoT | Internet of Things |
| Jpg | Joint Photographic Expert Group |
| KPI | Key Performance Indicator |
| LPP | Lean project planning methodology |
| PI | Performance Indicator |
| R&I | Research and Innovation |
| PPC | Percentage Plan Complete |

# 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 behavior 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 Purpose of the document

The work carried out in this report serves to develop a set of Performance Indicators for planning and controlling construction site activities, ranging from supply chain logistic planning, resource allocation, to site layout planning that allow site managers to steer all planning and control activities towards productive, resource efficient, and safe construction. This document summarised work performed in *Task 4.1 KPIs for productive, resource efficient, and safe construction work* and is a basis for the development of the ASHVIN applications and tools proposed to be developed in Work Package 4. In the project Key performance indicators (KPI) are the main criteria to be defined by which the construction process will be judged. It means that the Key Performance Indicators are:

- Productivity
- Resource Efficiency
- Safe construction work

While the Performance indicators (PI) are a number of related and quantifiable and measurable sub-criteria that constitute a KPI.

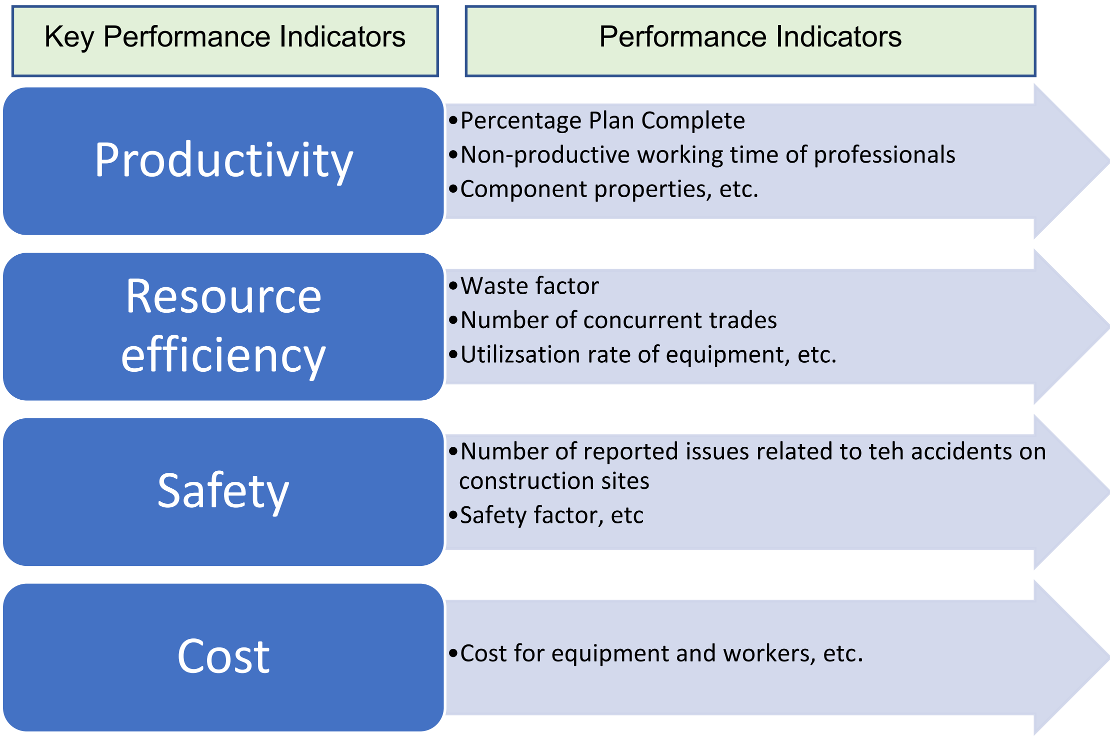


*Figure 1 Definition of Key Performance Indicators and Performance Indicators for ASHVIN project*

The target groups for this document are consortium partners of the ASHVIN project (tool developers and partners responsible for demonstration sites), construction management staff representing the main contractor (in particular site managers and engineers), subcontractors and investors (in particular technical supervisors).

## 1.2 Structure of the document

The document is structured into 7 main sections. First part of work is related to review of the literature, interviews conducted with experienced site managers and internal workshops that were performed among the project partners. Chapter 4.0 presents the ASHVIN tools that can support the productive, resource efficient and safe construction works. Next step is selection and description of the most appropriate Performance Indicators that can be implemented during the construction works on ASHVIN demonstration projects and constitute Key Performance Indicators. The report ends with the implementation plan that describes the most appropriate Performance Indicators for the three construction projects:

- Demonstration site #4 Logistic hall construction in Germany,
- Demonstration site #5 Kineum office building in Sweden,
- Demonstration site #6 Office buildings in Spain.

## 1.3 Selection Approach

Based on the analysis of Performance Indicators performed during the literature study, interviews with site managers and monthly internal workshops, a group of Performance Indicators was selected. The indicators need to contribute to productivity, resource efficiency and safe construction works and be possible to calculate based on digital twin data with the support of ASHVIN tools. Each indicator is characterised by a short introduction, data collection protocol and related ASHVIN tools. The tool providers were asked to analyse the Performance Indicators and make recommendations concerning the possible development and feasibility of the indicators. Final exercise is to verify and select the most appropriate Performance Indicators for each of the three demonstration projects that will have a construction phase. Selected performance indicators will be calculated with the support of ASHVIN tools and will contribute to achieving project impacts.

# 2 LITERATURE REVIEW

## 2.1 Introduction

Many companies are using Performance Indicators to compare their construction projects and to assess how the strategic goals of the company are fulfilled. However, the construction industry lacks objective benchmarks, or a way to measure excellence across the industry. One reason for the absence of industry benchmarks is the lack of centralized data necessary to establish standards. All contractors using digital technology to manage their construction projects are generating data and information; however, many say they lack a single place to aggregate that information and knowledge of how to use it in a meaningful way. Well defined Performance Indicators can help companies to better measure project outcomes and to better control the construction works. In addition, utilisation of performance indicators and digital twin technologies lead to better scheduling forecasts, better allocation of resources and optimization of equipment usage, reduced number of accidents on construction sites and reduction of costs on construction projects.

Managers on the construction site, supervisors and investors can use performance indicators on emerging structures for monitoring of:

- Progress and duration of various construction works (e.g., pouring the concrete, installation of the facade panels, construction of dry-wall elements.),
- Equipment usage (e.g., cranes, scaffolding, delivery tracks),
- Health and Safety conditions
- Labour productivity
- Deviation from original planning
- Waste disposal
- Use of available on-site space
- Cost

## 2.2 Performance Indicators impacting on resource efficiency

The construction sector is the largest consumer of raw materials in the EU and construction and demolition activities account for about 33% of waste generated annually.[1]While efforts towards sustainable construction have increased, these have largely covered fragmented segments of the construction industry—i.e., focusing only on energy issues or carbon emissions—thereby omitting the “big picture”. Therefore, a more comprehensive perspective is needed; one that more fully considers the trade-offs between different types of resources (i.e., materials, energy, equipment) and the functionality of the built object (social aspects) over the life-time of a built object.[2]

Construction and demolition waste (CDW) accounts for more than a third of all waste generated in the EU. It contains a wide variety of materials such as concrete, bricks, wood, glass, metals and plastic. It includes all the waste produced by the construction

[1] Resource-efficient construction: A systemic approach to sustainable construction, Eco-Innovation Brief #4, 2011

[2] The European Environment State and outlook 2010. Material resources and waste. European Environment Agency

and demolition of buildings and infrastructure, as well as road planning and maintenance. That's why the European Commission introduced a new protocol on construction and demolition. Its overall aim is to increase confidence in the Construction and Demolition waste management process and the trust in the quality of Construction and Demolition recycled materials. This will be achieved by:

- Improved waste identification, source separation and collection,
- Improved waste logistics,
- Improved waste processing,
- Quality management,
- Appropriate policy and framework conditions.

This Protocol has been developed for application in all 28 EU countries. According to (Kourmpanis, 2008) knowledge of the generated quantities of every waste stream constitutes the main parameter required for the development of an appropriate scheme for its management. Construction & Demolition (C&D) waste is one of the waste streams for which data related to the quantities generated is not easy to obtain. The data kept by the producers and authorities involved does not refer to waste quantities but could be used as a basis for the extraction of quantitative data, by using appropriate supporting calculation tools. All the producers and authorities involved in the generation and management of C&D waste (sources for the collection of data related to this waste stream) should be recorded and an inventory program could then be applied to obtain all the necessary data and information for the determination of the quantities of C&D waste.

At every stage of the construction process there are different opportunities for different professions in construction to reduce waste, and reuse or recycle products, components, and buildings, and for materials to move up the waste hierarchy so that ultimately material resources can continue to flow around a circular economy. These opportunities are available to clients, designers, material suppliers, product manufacturers, distributors and construction and demolition contractors. The waste management industry is also important in enabling those in construction to improve their waste performance. The government has a key role to play in the setting of policy and regulation, as a construction client and building owner, as well as ensuring statistics are gathered to measure and monitor material use.[3]

Construction projects are complex and dynamic in their nature. One of the main resources and constraints that affect the delivery of construction projects is the space available on site to execute site activities directly or indirectly (Dawood et al. 2005). Spaces on construction sites have become more and more critical to the extent that new business models have emerged in Europe and the UK, where logistics companies use space buffers to free site space capacity, especially for construction projects built

[3] Zero Avoidable Waste in Construction, A recommendation from the Green Construction Board, 2020.

around large and busy cities. In addition, construction projects are currently characterised by a high degree of fragmentation and specialization, which shape both the work on site and in the upstream supply chain (Kassem et al. 2012). Activities on construction sites are usually performed by multiple trades who require, at any point in time, different workspaces such as: working areas for laborers; material storage; equipment, and support infrastructure.[4]

## 2.3 Performance Indicators impacting on productivity

Even minor drops in the level of safety and productivity have a negative impact on working time and contribute to delays, which also affects the growing cost losses (Nabi, El-adaway, Dagli, 2019). According to Nabi et al. (2019) **initial labour hours**, **maximum production rate**, **labour productivity**, **remaining work** and **target production** were proposed as factors that may affect safety performance and productivity on the construction site. **Initial labour hours** represent the number of daily working hours multiplied by the number of workers. **Maximum productivity rate** is the highest possible labour productivity rate which can be obtained at current projects. **Productivity rate** factor should increase as a learning curve[5]. With time, as the workers acquire necessary knowledge to obtain the task and get higher familiarity with current work, the productivity is expected to increase. The two equations needed to calculate **labour productivity rate** and **productivity rate** were presented with the remaining factors used as output. Additionally, one of the formulas allows one to consider the seasonality of work at every stage of time because the productivity of blue-collar workers is strongly dependent on weather conditions.

## 2.4 Performance Indicators impacting on safe construction works

According to studies of Winge, Albrechtsen and Arnesen (2019) the construction industry in Europe still has one of the highest fatal accident rates, greater than one in five accidents at work. The article provides an overview of 12 different construction projects. The constructions were mostly new buildings, museums and university buildings, and rehabilitations of old buildings. Some of these projects included demolition and groundworks. As a result, it was possible to develop 16 factors that, to a greater or lesser extent, contributed to the classification of the project as a project with a high level of security or with a low level of security. The following indicators were used to develop the results:

- WH - **working hours** recorded by the main contractor, subcontractors, and hired workers, excluding designers' working hours.
- LTI-rate - (**Lost Time Injuries**) per 1 million hours of work. These are injuries that result in more sick leave than just the day of injury. Reported by contractors to the client.
- MTI-rate - (**Medical Treatment Injuries**) for 1 million working hours. Reported by contractors to the client.

[4] https://www.itcon.org/papers/2012_13.content.07761.pdf.

[5] A learning curve is an interrelationship between a learner's performance on a work or task and the number of attempts or time which is required for the task to be done; learning curve is a process where employees develop a skill by learning from their mistakes; it can be presented as a direct proportion on a graph

- TRI-rate - (**Total Recordable Injuries** LTI + MTI) per 1 million working hours. Reported by contractors to the client.
- RUOs and SDs - (**Registered Unwanted Occurrences** and **Site Deviations**) include accidents and potentially accidental situations, as well as deviations from the regulations registered by contractors regarding mainly safe work analysis, work instructions, lack of personal protective equipment, scaffolding failure, no hazardous zones have been specified.
- WTR - (**Willingness To Report**) RUO and SD per 1000 working hours.

There are two main types of safety indicators: lagging and leading indicators (Poh, Ubeynarayana, Goh, 2018). Lagging indicators (also negative or reactive indicators) are measuring workplace safety and health outcomes such as **illness** or **injury rate**. Due to the delayed nature of lagging indicators, developing the suitable leading indicators to help managers assess the safety and health risk of workplace is needed. The leading indicators (also positive and proactive indicators) are measuring activities at workplace, events and conditions which may determine safety and health outcomes, e.g., **number of inspections**, **safety climate** measures and **aggregated training effectiveness score**.

According to studies of Choe, Seo and Kang (2020) the most popular safety factors are related to **total recordable incident rate**, which are lagging indicators. It also turned out that more than half of the examined subcontractors declare that they use only **injury rate** as a safety indicator. Moreover, approximately 27% of workers do not report their injuries to their supervisors. Furthermore over 70% of white-collar workers said they use many of safety performance indicators on the construction site, while over 70% of blue-collar workers complain that **total recordable incident rate** is the only used safety performance indicator. The data was compiled on the basis of 341 survey data items collected from general contractors and subcontractors, both blue collar workers and white-collar workers in South Korea (Choe et al., 2020).

It is worth paying attention to the level of pollutions in the air because it can have a negative impact on health. According to Khamraev, Cheriyan and Choi (2021) 70-80% of all particles of suspended dust come from construction projects. The formula to calculate **mean daily dose exposure** (mg/kg x day$^{-1}$) to a particulate matter[6] was proposed as an factor related to health indicators. The input data from which it is possible to use the formula is **concentration of particulate matter** (μg/m$^3$), **inhalation rate** (m$^3$/h) and **exposure duration** (years). Health risk performance was assessed among workers in residential buildings in Beijing. Results showed that blue collar workers of template and steel zone had the highest health risk, while blue collar workers in the office zone had the lowest health risk.

Construction industry is one of the noisiest to work in, and 14% workers exposed to blaring **noise** have considerable hearing difficulty (Zitzman, 2018). According to that, **noise** can be considering as a pollutant which has an impact on workers' health.

[6] Particulate matter (also particle pollution): the term using for a mixture of solid particles and liquid droplets that can be found in the air.

Kantova (2017) and Zitzman (2018) had identified sources of noises on the construction site and presented support software's for calculation and evaluation of **noise**. Ways to reduce **noise level** were also presented.

In order to improve safety on the construction site Zhang et al. (2015) propose real-time location tracking system for workers, and to visualize workspace use. **Workspace occupation** parameters were computed depending on work activity level.

## 2.5 Performance Indicators impacting on cost reduction

The economic feasibility of building renovation was identified as a fundamental in many studies employing performance indicators related to the building renovation projects (Kylili et al., 2016). Performance Indicators can be related to direct, indirect, and shadow costs. Direct costs economic performance indicators: **capital investment**, importance of **cost**, **economic performance, and affordability** (1-10 priority level scale), suitability of **initial cost**, **lifecycle cost**, **project profitability**. Indirect costs economic performance indicators: **adverse effect on the level of ground water** (being agree or disagree in 1-5 scale), **impact on tourism values**, **employment of labor**, **adaptability and flexibility** (1-10 priority level scale), **minimum variations cost** (being agree or disagree in 1-5 scale), **no increase material cost** (being agree or disagree in 1-5 scale), **stable labor costs**, **resetting cost of people**. **Stable labour costs** were explained as keeping the cost of work on the project at a constant level. **No increase material cost**s were explained as keeping the cost of materials used in the project at a constant level. All economic performance indicators of direct and indirect cost were presented for the sustainability of building renovation projects according to the research papers review (Kylili et al., 2016). **Capital investment** can be defined as a sum of money acquired by a company (Kenton, 2020). **Initial cost**, **lifecycle cost, impact on tourism values, resettling cost of people** and **employment of labor** are defined as being very suitable or no suitable in 1-5 scale. **Adverse effect on the level of ground water** was included in the economic performance indicator because the stakeholders would require minimizing the negative impact on the groundwater level, which would lead to an increase the cost of the project (Kylili et al., 2016). The **Shadow cost** factor is an environmental performance indicator measured in the currency euro. It represents the highest permissible level of environmental cost for the government per environmental damage unit that the government can endured (Kylili et al., 2016). Not explained indicators listed previously were only mentioned as important due to research review.

Performance factors are often used to minimize the cost of a project (Gabbar, Xiaoli, Abdelsalam, Honarmand (2014). Several economic indicators can be identified. **Lifecycle cost** or capital cost indicator can be used to assess the economic feasibility of available systems. **Operation cost** or generation cost can be used to determine fuel consumption and then can be related to fuel price. **Risk cost** can be analyzed as the equivalent cost for damages and delays caused by power interruptions. It mainly depends on the probability and duration of the interruption. The above factors have been proposed in order to determine the most appropriate energy source, among the wind turbine, solar panel, battery and fuel cell.

**Percentage of rework** can be used as performance indicator according to the study of Hegazy, Said, and Kassab (2011). Rework can be defined as the effort of re-doing some activity or process that was at the first time done incorrectly. The rework percentage can be calculated as a percentage of the total activity quantity. All data should be obtained from site reports. The research was made as the delay analysis in construction industry in Canada.

It is up to date to develop or to use low-cost sustainable materials as far possible. According to the studies of Arun, Baskar, Geethapriya, Jayabarathi, and Angayarkkani (2021), **the cost-effective construction materials** can be considered as a performance indicator. As cost effective construction materials e.g.: fly ash, foundry sand, expanded polystyrene, coconut shell, welded mesh, and geogrid can be used. Furthermore, using recycled expanded polystyrene as a construction material, it will be more friendly to environment. Because of that, by using less expensive and more common materials in current region, up to 26.11% cost of total building cost can be saved. Also, transportation cost can be reduced up to 30%, when more regional available materials could be used.

Due to Hammad, Akbarnezhad, and Rey, (2016) **the transportation cost** can be used as performance indicator. It is often the site engineers or project managers task to positioning temporary facilities on the construction site to minimize transportation cost between these facilities and minimize the cost of the materials handling. Minimisation of the transportation cost can be easily calculated, when the cost of operating transportation equipment, the travel frequency between facilities, and the distance between facilities are known.

According to the SWS Heating project (2019) the following economic indicators were identified: **generated cost savings** and **production cost**. **Generated cost saving** is the expected cost saving which is generated by the energy storage system in a group of buildings. Must be referred to a day or year period and characterized by specific number of cycles. Production costs include expenses like labour, raw materials, and consumable manufacturing supplies.

# 3 INTERVIEWS

## 3.1 Introduction

To be able to understand the importance of performance indicators that support planning and control activities towards productive, resource efficient and safe construction several interviews with a specific target group were conducted. The target group for these interviews were site managers who work closely with the construction site and can give vital insights on the influences for the KPI's during their past or even future projects. The interviews were conducted with workers of construction companies as: NCC AB (Sweden)[7], Schlaich Bergmann and Partners[8] (Germany), KB Doraco (Poland)[9]. The approach was to question these site managers, ask them about the indicators that were already put in place and their influence on productivity, resource

[7] https://www.ncc.com/
[8] https://www.sbp.de/en/
[9] http://www.doraco.pl/en/start/

efficiency and safety construction. Moreover, their insight on possible new indicators that could be vital for future references was discussed.

## 3.2 Outcome from the interviews

### 3.2.1 Cost & Revenue

Besides asking the interviewees about the impact of design, planning and executional mistakes done during a project, they were asked to project their experiences and give us an insight on what usually has a great impact on the cost & revenue of a project during the construction process. Seventy five percent of the asked site managers stated that the purchase of materials and items is a big factor that influences the cost of a project. Wrong purchases increase your cost and waste the time of your workers and therefore also the time from the project itself, while also cutting off the flow of the productivity of the workers. Major changes or client changes during a project was another indicator as an impact on the costs, with half of the interviewees stating that claim. And the same number of interviewees stated that the mistakes and the correction of tasks is something that hinders the revenue from growing. Major changes will not influence the time frame, since that does not change no matter what, but it makes it more difficult to finish in time. While mistakes slow down the process of the project and forces one to redo tasks which is an additional increase in cost. Another interesting point was the number of geotechnical examinations done, since it will make it unpredictable to know the depth of clay there is or if there is a rock hiding. These aspects and unpredictable results could cost time and therefore an increase in expenses.

*Table 1 Overview* of the discussion about cost and revenue aspect on construction site

| Key Performance Indicators | Interview source | Reference |
|---|---|---|
| No. of wrongly/ incorrect purchased materials during a project | First | "[...] that you get enough materials, not too much, not too less; it is not only the price you pay for the product but also to get it inside, you need to get the materials right place." |
| | Second | "[...] correct purchases and give them the best conditions to work in, things usually go on time I would say" |
| | Fourth | "Ordering the wrong material or ordering too much material, not trying to save material. Hording the material that we do not need" |
| No. of mistakes made during a project | First | "[...] if you make a mistake that will cost you a lot of money" |
| No. of work that has to be corrected or redone | Fourth | "Then we have to make correction to the things that we did in the past, that is the first thing"<br>"[...] doing the same job multiple times" |
| No. of major changes/client changes during a project | First | "[...] there is a major change during the project, which is not supposed to affect the revenue of the project. But on the other hand, your timing schedule remains the same and you do not get any more time and have still to finish it in time. That can possibly change the planning of your revenue and you will not get the spent cost back because of these major changes." |
| | Third | "Changes are the thing that make it the most complicated and then also cost expensive." |
| No. of geotechnical examinations done | Second | "[...] geotechnical examinations have not been thorough enough, and we get a different depth of clay, or the rock is different than predicted" |
| | Third | "Soil problems are something you often cannot expect or expect completely" |
| Findings of archaeological findings | Second | "[...] archeological findings here that made the whole project come to a hold for almost a month." |

### 5.1.2 Productivity

The discussion on productivity was to ask for the impact of the project delays and how we can create a work environment with mostly active and passive work in play. Fifty percent of the site managers claimed that the tidiness and the cleanness of a site is crucial for the gathering, grabbing and flow of the work. An interesting pay system was introduced in one of the interviews, where the workers get paid for the performance they do, which motivates the workers to not only work fast but also precisely. That paying system works for smaller projects better than for bigger ones. An additional good indicator for productivity is to compare the current progress and costs spent to the budget that was set in place from the beginning. Another manager claimed that if he had to look from the outside into a construction site, his first indication of productivity is to compare the time that the machines are actually working against the time they are standing still.

*Table 2 Overview* of the discussion about productivity on construction site

| Key Performance Indicators | Interview source | Reference |
|---|---|---|
| No. of cleaning & organizing tasks/procedures during a project (also dictates safety & productivity) | Second | "[…] I would look if it were tidy and well cleaned because often it goes hand in hand with the economics as well, if it is really chaotic, mostly the guys would go around looking for stuff and they would trip over and injury themselves as well." |
| | Third | "[…] if waste is laying everywhere on site, then it cannot be productive cause then they just run around and do everything but never clean up their site and that is something"<br><br>"[…] look everything looks good and clean here then they will know what to do and how they will do it" |
| Installation of a paying system according to performance (works for smaller projects better than for bigger ones) | First | "[…] workers that we employ get paid by their performance"<br><br>"Because let's say they are not doing a good job, they would have to go back and fix it. And it will affect the number of hours that they invested and therefore get paid less" |
| Current progress and cost vs. budget | Second | "If you measure how much you do and how much it cost, then you can compare that to the budget. So, you get a really nice indicator." |
| Amount of times the project is on hold | Second | "[…] It is also demoralizing to wait and stand around and don't get the flow in the work because everybody wants to feel the flow of the work going" |
| Time between design finishing and project start | Second | "I mean if it is something that is really rare or one of a kind and you get the drawing late and you get the delivery time could be super long." |
| Amount of time machines are working/standing still | Second | "[…] if machines are standing still or even more if you are digging out the prince and you have a certain amount of trucks standing and waiting, they should never be standing." |

### 3.2.2 Resource Efficiency

Other than the questioning of the efficient usage of the available space on a construction site and the reuse of material for environmental reasons, the interviewees' perception of the biggest influences was analysed. A very interesting method to keep up with the evaluation of the space used on a construction site, is the usage of drone footage, which was stated by a site manager from Sweden. Half of the interviewees expressed that the amount of time between a delivery and the usage of these materials are crucial not just for resource efficiency but also for the productivity of a site. Since the usage of materials after delivery, create more space to work with. Fifty percent of site managers stated that the number of unexpected deliveries influences the time, the resource efficiency and also cuts the workflow of the workers. Another interesting method was to have a graphic view of the payload of each truck. The advantage of the method is to know exactly when a car's load is 100 percent used or not. The interviewees company saved up to 70.000 extra truck loads.

*Table 3 Overview of the discussion about resource efficiency aspect on construction site*

| Key Performance Indicator | Interview source | Reference |
|---|---|---|
| Amount of time between delivery and usage of material (more space to work productivity & resource efficiency) | First | "These deliveries are supposed to be used in the next few weeks, so you don't have a warehouse of stuff that will be lost forever on the site" |
| | Third | "[...] think often it is not necessary to have a bunch of things on site but having on site what you really need. And then you don't have a bundle of materials laying there, you automatically have more space to work." |
| No. of unexpected deliveries during a project | First | "Unexpected deliveries where someone just shows up with a truck and that is 99 percent of the time that it does not work, so then we will have to send them away." |
| | Fourth | "If it is not scheduled then we will be like "there is a delivery on the gate" then we are running, trying to take people from their jobs and put them to secure the equipment there, handle tools and we are basically wasting time." |
| No. of recycled materials | First | "Well, we are being certified as environmentally friendly building and that includes waste management that we have to recycle and sort out everything" |
| Drone footage used for evaluation of space usage | Second | "[...] drone footage, which we do every week, and we use those drone images, to draw really simple on background photos" |
| Color of steel | Second | "[...] the rebar arrives for the concrete, it should always be kind of blackish in the color because once it has been laying around for too long, it gets that orange look" |
| Pay load as graphic view for usage of truck | Second | "And every truck has its pay load in sort of graphic view, so the guide who is doing the excavating, he can see on a progress bar when the cars loaded to exactly 100 percent. Because otherwise, if you load too much, you get a fine from the traffic authorities and if you load too less than it is money loss" |
| Amount of reused materials | Second | "Reuse this gravel which is also very environmentally friendly" |
| Amount of cleaning & organizing tasks | Fourth | "[...] the space is well used, if it looks neat, organized and the material is sorted then for me it is well used." |
| No. of damaged materials from deliveries | Fourth | "[...] so, if the material comes damaged then we cannot progress with the construction, and we do not have |

### 3.2.3 Health & Safety

In addition to the incident rates, if fatal or non-fatal, other important aspects like the cleanness and the neatness of a construction site were essential. Seventy five percent of the interviewees said that the constant cleaning and organizing of materials and the site as itself, helps immensely to create a safer environment since it prevents workers from falling over and injuring themselves. Another aspect was to have regular safety walks as a site manager and to make sure all the workers are doing their job and checking on every safety measurement and evaluation. As a common statement, all site managers were highlighting the sheer importance of being safe comes from the mentality of the workers and a constant communication is important to underline that.

*Table 4 Overview of the discussion about Health & Safety aspect on construction site*

| Key Performance Indicator | Interview source | Reference |
|---|---|---|
| No. of organizing and cleaning tasks during a project | Second | "[...] with the tidiness and the cleaning of a construction site. I mean, if you see a lot of debris laying around, obviously the workers will fall and injury the feet and stuff or even worse. It is also really easy to see if the work site has a thought for fences and stuff on high levels that you can trip on." |
| | Third | "[...] waste everywhere around, the cleanness of a site definitely." |
| | Fourth | "[...] safe would be clean and neat space that people are working in, tools that are not damaged and equipment not torn or dirty" |
| No. of safety walks/inspections | First | "Every week, we are going on a safety walk on site." "[...] bring everything we see that is dangerous or unsafe. It can be scaffoldings, shafts or too much dust." |
| Support of safety equipment | First | "[...] we make everyone wear safety glasses" "[...] having the chin straps for our helmets" |
| No. of accidents | Second | "[...] if somebody really gets hurt or even worse or maybe even passes away, then construction will stop for several days, and it costs so much money." |
| Amount of supportive structure for tower projects | Third | "[...] if you think about some temporary structures that need to support something, just temporary, you see how they build this temporary tower for example. Did they put some nail and wood together or did they something which looks safe? This makes a big difference." |

### 3.2.4 Summary

There are a few indicators that can be contribute to not to just one category of Key Performance Indicators (Productivity, Resource Efficiency and safe construction works), but to few of them. The number of times the site is getting organized and cleaned influences not only the safety of a site but also the productivity. In addition, the number of tasks that have to be redone/corrected influences the morale of the workers and therefore the productivity of the work as well as the costs and the resources that are being used to finish up that task. The indicators that were mentioned from more than one interviewee are highlighted because of their clear importance for most site managers. Changes, unorganized sites, correction of work & detailed planning between design finish and project start are indicators that will help set up benchmarks and possible enhancements for future projects.

# 4 ASHVIN TOOLS SUPPORTING KEY PERFORMANCE INDICATORS

This chapter presents and introduces tools that will be developed under the ASHVIN project and support construction works and calculation of relevant performance indicators. The following Figure 1 shows the various tools to be developed in relation to the Ashvin platform. Each of the tools interacts with the data in the platform such as geometrical and alphanumeric data. Visualisation of data is done in the respective tool through dashboards and 3D-viewers. Collectively the tools and especially the dashboards provide a rich environment to consider and manage the performance indicators.


*Figure 1 Tools to be developed in relation with the Ashvin platform.*

## 4.1 Construction monitoring tool with productivity and safety KPI decision making dashboard (4DV-C )


Partner DTT is developing 4D (3-dimension x-y-z and time as 4th dimension) tool on top of the available digital twin platform of DTT, which is aimed to visualize past construction activities based on certain activities tracked by the digital twin platform. One of the key features of this tool is that it allows to plan future construction sequences and site layout options based on accurately mapped past activities. Also, it is useful in identifying potential conflicts and finding potential optimizations. Therefore, with the help of this tool site managers can understand, control, and manage construction sites which are under consideration of actual digital-twin based data.

In a simple word this tool is visualization platform of 3D model of infrastructure as well the construction site equipment. The 3D model shall be import in the platform along with meta data and then further connected by available IoT sensors and other data sources on site. Data shall be analysed via methods developed by partner CERTH and then the model will be updated. Once there will be any activities need to watch from past, stakeholder can use the time scroll bar for a specific day and time and generate reports or graphs about the process happened. This tool will be very helpful for any discrepancy happened during or after the construction phase. Not only this, during maintenance phase this tool is highly effective to understand root cause of damage during the complete life cycle of the infrastructure.

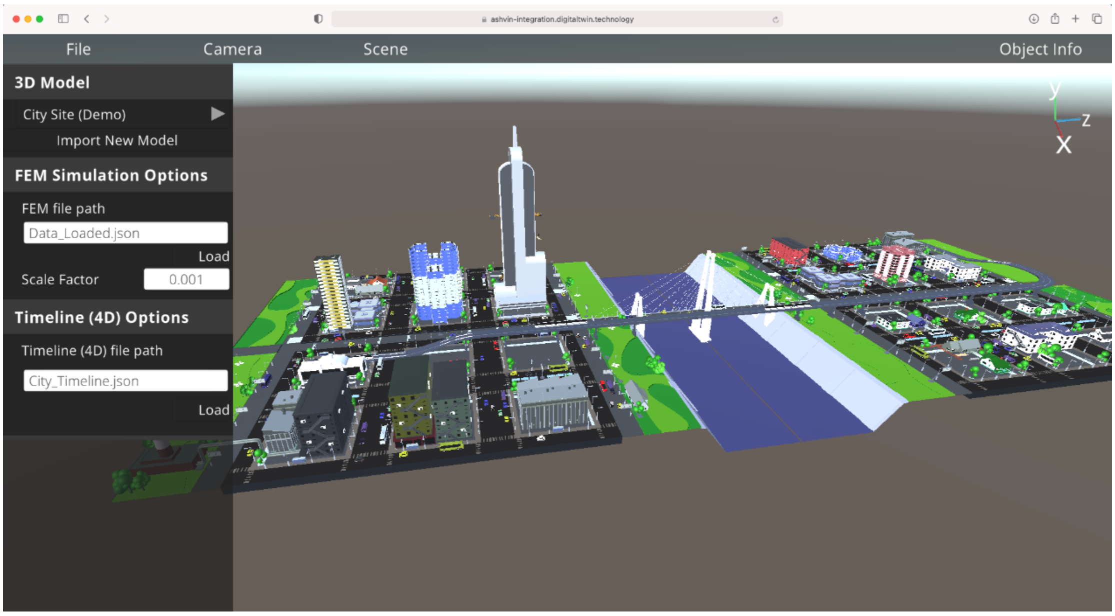


*Figure 2: Ashvin digital twin platform*

Stakeholder can import Industry Foundation Classes (IFC)[10] format files directly via web browser, if the stakeholder has proprietary file formats like Revit[11], Rhino[12] etc. then the workflow will include first manual work of converting the file into the digital twin platform. The tool let visualize the meta data and as well the Finite element method (FEM)[13] data in real-time via connecting to FEM tool with Representational state transfer (REST)[14] application programming interface (API)[15].

## 4.2 Privacy ensuring safety management, simulation, and training tool (SMT)

Partner DTT is developing this application on the top of existing GIS platform, that will allow safety managers to understand possible safety hazards on site and to analyse past construction activities without being able to target specific workers personally. As a high-risk industry, safety accidents in the construction industry will have a major impact on the social economy, people's lives, and natural environment. Therefore, preventing the construction safety damage is essential to promote workers' safety and health, maintain the productivity level of construction projects and reduce compensation for work-related injuries.

This tool will be extension to 4DV-C where construction workers, equipment & machineries, and other objects shall be tracked on construction site using game engine platform of DTT in simulation form for the sake of privacy of each worker. Figure 3 shows the image of DTT tool for railway in Germany to monitor people movement with proper privacy maintained.

Figure 3: DTT tool for people movement tracking on train station

Tracking shall be done via BLE beacons. Existing DTT platform for people tracking on GIS map is shown below in Figure 4 which will be upgraded to DTT game engine platform with 4DV-C.

[10] https://en.wikipedia.org/wiki/Industry_Foundation_Classes
[11] https://en.wikipedia.org/wiki/Autodesk_Revit
[12] https://en.wikipedia.org/wiki/Rhinoceros_3D
[13] https://en.wikipedia.org/wiki/Finite_element_method
[14] https://en.wikipedia.org/wiki/Representational_state_transfer
[15] https://en.wikipedia.org/wiki/API

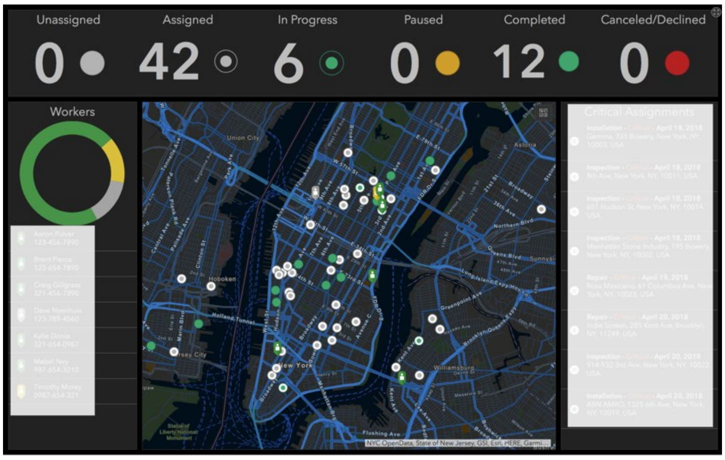


*Figure 4: DTT GIS map*

## 4.3 A configuration management tool to track as-designed and as-built, as well as, to allow for seamless commissioning (CMT)

Partner DTT is developing software which allows for establishing and maintaining consistency among certain requirements, design, configured items, associated construction, operations and maintenance data, equipment and other enablers throughout the full project lifecycle based on digital twin data. This tool is also the extension of 4DV-C tool for comparing design model with actual construction progress for the very basic concept of as-built vs as-design. This tool will be a screen software that will be representing the design model and actual construction model at same time.

## 4.4 Simulation-based real-time construction site and logistics planning tool (DES)

Partner TUB is developing this tool for simulation of construction processes to achieve more productive and safe construction sequences. Stochastic digital twin data of equipment movements are collected by IoT sensors on construction site. These data are evaluated within R, a statistical programming language, to gather information about the duration of activities. Thus, more reliable forecasts about the duration of construction processes are enabled and, overall, the whole construction process can be planned enhanced by (micro) discrete event simulation. Typical construction patterns can be combined in a modular approach for easy application of the DES tool. It is only needed to fill in the duration of activities, which are calculated due to the data collection. Subsequently, it is possible to compare different construction possibilities. The allocation of resources and the material supply can be optimised to increase the utilisation rate of equipment. Furthermore, it is enabled to coordinate construction works to avoid hazardous situations to reduce the number of accidents.

Furthermore, due to the data collection of digital twin data in (near) real time it is facilitated to track and control the construction process within the DES tool. Hence, if deviations of planned construction sequence occur, these are much faster identifiable by construction managers and in the following the construction managers can react faster to prevent further losses in construction process. The DES tool can suggest executing other construction activities, which are not affected by the reason of the deviation.

## 4.5 Multi-physics model matching tool for status assessment of bridges and buildings (MATCHFEM)

Partner UPC is developing a tool that matches physical simulations with the Digital Twin requirements established in Ashvin project. The tool is based on computational geometry embedded within BIM-enabled existing platforms such as Grasshopper (Rhino and Revit). Primarily, the tool is programmed using C# and Python with open-source code and it serves to the development of physical simulation needed in several of the demonstrators deployed in Ashvin. Structural simulations in reinforced concrete (RC) structures as well as Prestressed Concrete (PC) structures are under development. One application of the tool is update of maintenance plans that can benefit from accurate predictions of the structural behaviour of the asset. The codes account for the nonlinear behaviour of the material as well as for the rheology (time-dependency) of the concrete. In addition, structural simulations of cable nets are under development.

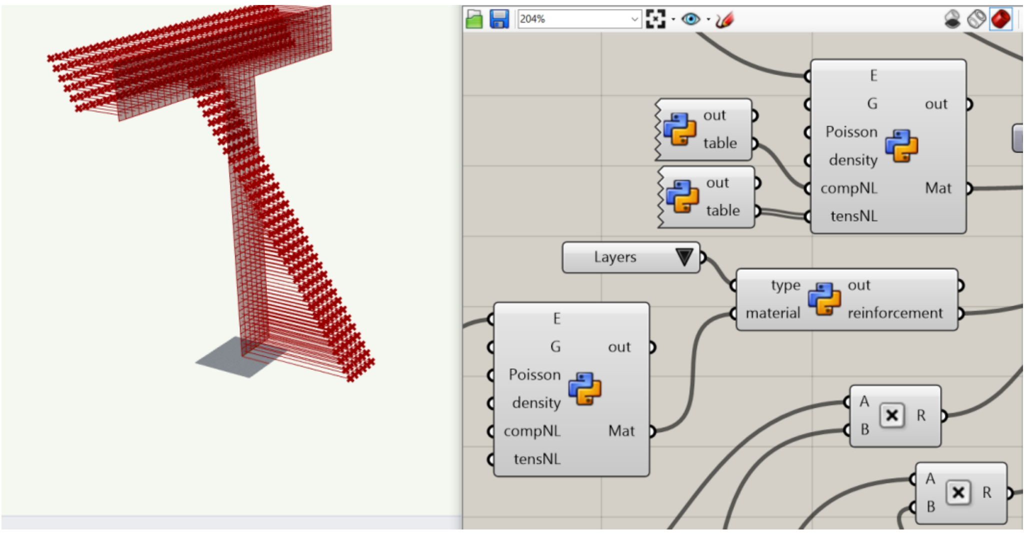


*Figure 5: MatchFEM preliminary development of RC structural cross-sectional analysis.*

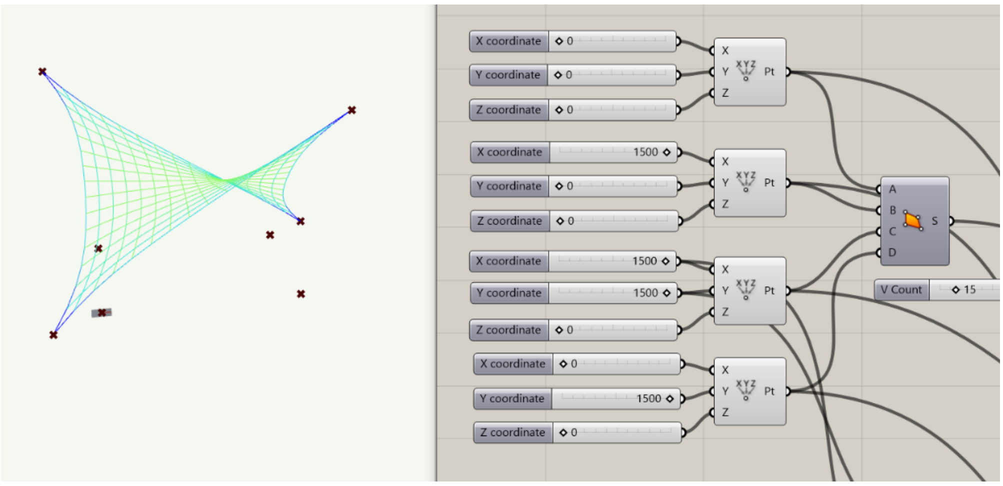


*Figure 6: MatchFEM preliminary development of steel cable nets*

Moreover, two features provided by MatchFem are pointed out: First, its capability to support structural analysis during sequential construction of RC and PC elements. This feature is of particular interest in the real-time safety assessment of assets during erection. In subsequent periods of the project, the rheology of the material as well as the appearance /disappearance of structural elements will be embedded within the tool. Second, its capability to couple to other existing simulation tools. Existing open-source multi-physics tools such as Fenics or existing Proprietary Licence Software such as Abaqus (Simulia) or PICD (CIMNE) will be coupled seamlessly to the Ashvin suite via MatchFem.

MatchFEM includes different implementations of methods that allow to stochastically adjust input parameters for different multi-physics simulations using sensor-based measurements. These methods allow for the accurate representation of behavioural digital twins. In this particular case, the casting sequence provides crucial information related to the concrete hardening, casting time and strength of the components.

Finally, it is important to point out that MatchFem is being developed in such a way input from sensors and from IoT platforms (Mainflux), simulations and output to Ashvin are connected using standards that can be also used for third parties.

## 4.6 Lean project planning methodology

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. Part of the method focuses on the overall flow in construction referred to as macro management which is based on the application of flow line scheduling. The planning and control of the prerequisites for construction tasks is based on the application of 4D models with a special emphasis on planning for safety, resource use and logistics. This is primarily done by space loading the 4D models. The 4D models are updated with data collected from site monitoring using scanning imaginary analysis and IoT devices for dust, sound, proximity and occupancy.

# 5 PERFORMANCE INDICATORS

## 5.1 Productivity

### 5.1.1 Percentage Plan Complete

#### *5.1.1.1 About*

Percentage Plan Complete (PPC) is an indicator to measure the reliability of a construction schedule. A construction schedule is one of the most important documents on the construction site and it outlines project timeframes/ milestones and tracks project progress to keep everything on-time and on-budget. PPC is part of the Last Planner® System of Production Control (Last Planner). With PPC one can improve the supervision of the schedule and increase productivity.

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[16].

The Last Planner System is organised in five parts according to the following figure. PPC is an indicator used to assess the weekly work planning and is part of the learning stage in which analyses are made of what a production team did.

A PPC of 80-90% is typically considered a good score. A score below 80% indicates a serious deviation from the schedule and should therefore raise awareness and warning flags to adjust the gap between the actual performance and the planned performance. Experience shows that if the PPC score is not actively managed, it will decrease.

[16] lean constructionblog.com

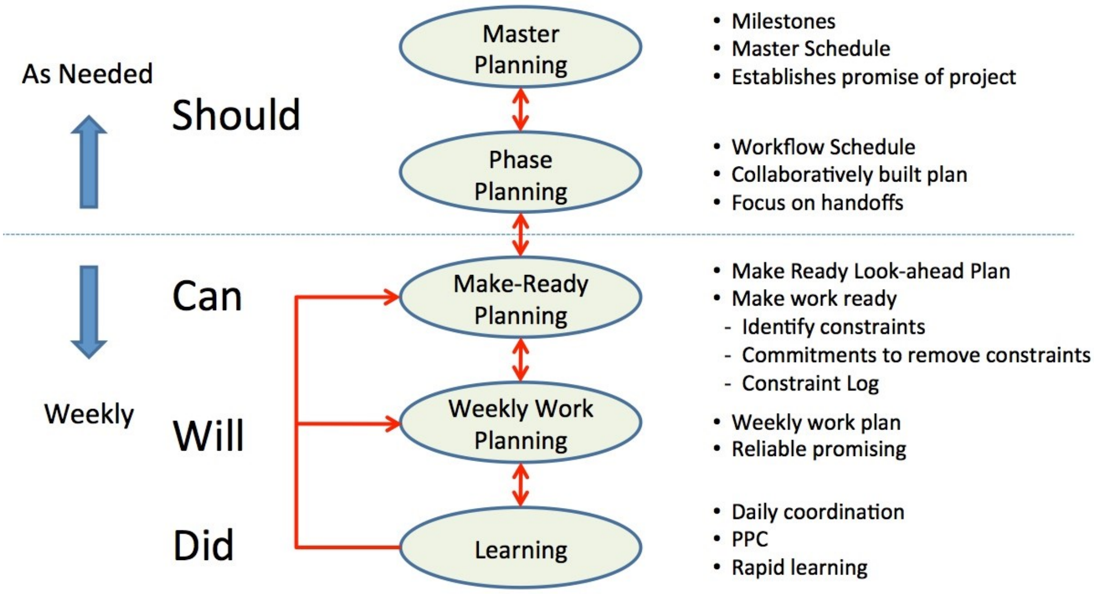


*Figure 7 Last Planner System (source: Leanconstructionblog.com)*

#### *5.1.1.2 Data collection*

Data for the metric is collected from the weekly work planning established ahead of a week's work on a production site. The weekly work planning in itself is the result of and based on a look-ahead plan and a high-level plan such as phase planning and master planning. The weekly work planning is established and committed to by last planners at the beginning of a work week. At the end of the week the last planners are asked whether the activities are completed. The answer is either yes or no. The data is typically collected in spreadsheets or directly calculated from a scheduling application.

#### *5.1.1.3 Calculation & ASHVIN tools contribution*

PPC = Activities completed as planned / Total activities planned

Typical interval for PPC-calculation is a week of activities.

The PPC can be shown using the 4DV-C tool developed by DTT within Ashvin by means of overlaying the planned schedule as 4D model versus the actual performed activity from that schedule by applying a colour scheme one can easily detect activities that deviate from the schedule, for example red is late or orange is early.

### 5.1.2 Non-productive working time of professionals

#### *5.1.2.1 About*

Time spent on indirect work i.e. making sure the prerequisites are in place for the execution of a construction task. Some indirect work is needed, but a lot of indirect work is considered waste. Such as: working with the wrong information, trying to find the right information, waiting for someone else to finish the preceding work, looking for the right material, looking for the right equipment, creating workspace to perform the work. A study in Sweden on an average construction worker's day on site showed that about 20% of the work is direct work, 40% indirect work and 40% is waste. Target of the ASHVIN project is less than 15%. With a calculated value of non-productive working time, it is possible to make changes in how work is implemented and increase productivity.

##### 5.1.2.2 Data collection

To collect data on how workers distribute their time, video can be recorded and thereafter analysed. By establishing different categories for time allocation, it is possible to classify how time is used.

##### 5.1.2.3 Calculation & ASHVIN tools contribution

The indicator for the share of direct work compared to all work is shown in a dashboard along with the 4D model and other indicators showing performance such as equipment use and space use.

To calculate the percentage of direct work, one divides the time spent on direct work with the total working time. A typical time interval for calculating direct work is a week of activities. The data collection is based on visual analysis that can partly be automated. The measurement interval is typically 15 minutes. The basic formula to calculate the percentage of direct work is time spent on direct work divided by total work time.

### 5.1.3 Component properties

There are various material properties to consider related to cast in place concrete that are affected by and are affecting the overall construction process and productivity. The following are considered in Ashvin project:

- Humidity of components
- Temperature of components
- Components structural integrity
- Adequate concrete vibration

##### 5.1.3.1 About

The humidity of components affects the possibility to proceed with subsequent construction work. A typical example is concrete for which the humidity must decrease to a certain level to be able to be covered with for example flooring material. Covering the concrete too early can result in damage such as mould and affect the quality of the material and the health conditions. Having to wait until the moisture level has decreased to an acceptable level can in some cases result in long and expensive waiting times. Depending on the concrete quality one can speed up the drying process, but this comes at a higher cost for the material.

Just as humidity, temperature has an impact on materials physical properties and in construction especially on the hardening process of concrete. What temperature the concrete has and its surroundings, sets the prerequisites for how long it will take for the material to harden and what properties the finished material will have. In lower temperatures it takes longer for the concrete to harden. By measuring the temperature of building materials, it is possible to determine when the specific construction activity is completed, and it is suitable to continue with following activities and can therefore increase productivity.

As mentioned above, hardening of components affects the possibility to proceed with subsequent construction work. A typical example is concrete for which the strength must increase to a certain level to be able to dismantle formworks and cast subsequent levels. Dismantling formwork too early can result in damage such as cracking. Having to wait until the strength has increased to an acceptable level can in some cases result in long and expensive waiting times.

Accessing the concrete too early can result in damage such as structural damage affecting the quality of the material and the health conditions. Having to wait until the moisture level has decreased to an acceptable level can in some cases result in long and expensive waiting times. Depending on the concrete quality one can speed up the drying process, but this comes at a higher cost for the material.

Vibrating concrete is almost always recommended since well vibrated concrete will be stronger than its ill-vibrated counterpart. This task requires energy, which should be thoughtfully invested. For instance, it is desirable that all standard concrete columns receive a fairly evenly distributed allocation of vibrating energy. Too much or too little energy yields to inefficiency of the energy resources or to jeopardising the quality of the concrete. Measuring standard elements, for instance, a set of columns, allows controlling and monitoring the amount of energy devoted to each individual member of the set.

#### 5.1.3.2 Data collection

To collect data considering humidity of components, sensors can be applied in or on concrete slabs. In addition to sensors, moisture measuring instruments such as a relative humidity meter can be used. The collected data can be categorised depending on material, space type and time intervals. Thereafter the data can be analysed accordingly. For collecting temperature data from building components, thermometers and other thermal detecting devices/sensors can be used. By comparing measured values to standardised values suitable for different materials, the data can be used as an indicator to see if materials are in suitable temperatures.

**Components structural integrity:** Automated reporting in the construction site. Measurements related to the response of the structural elements when subjected to different loading can be tracked. Strain gauges on concrete surfaces can provide information during relevant episodes such as pre-stressing or unshoring slabs. These sensors are contact-based. On the other hand, systematic laser scanning of the concrete slabs during relevant episodes can provide information about the vertical displacement of the slabs during sequential loading.

**Adequate concrete vibration:** Total amount of time can be tracked by adding vibrating sensors on key zones. Accelerometers can be coupled directly to the vibrating machine or indirectly to the formwork. In either case, acceleration will be detected while vibrating. Signals can be sent automatically to the cloud service and data can be treated afterwards. For instance, casting one isolated column may last 20 minutes. Recording acceleration signals can help measuring the proportion of time this isolated element is receiving energy related to the needed vibration.

#### 5.1.3.3 Calculation & ASHVIN tools contribution

By measuring moisture levels in materials and/or spaces at specific predetermined points in time and comparing the values to recommended values. Interval for calculation varies depending on type of material and space. Devices will measure the humidity of walls and slabs, also sensors will be applied in conjunction with the actual delivery of the concrete.

For measuring components' temperatures, Celsius (°C) or Fahrenheit (°F) can be used. Interval for calculation varies depending on when construction projects conduct temperature dependent activities. Devices will measure the temperature of walls and slabs, also sensors will be applied in conjunction with the actual delivery of the concrete.

Humidity levels and temperatures of components are shown in a dashboard along with the 4D model and other indicators showing performance such as equipment use and space use.

**Components structural integrity:** This factor can be calculated in "CCCC" = day of casting completion-day of beginning of the construction works. Tool MatchFEM provides time-dependent structural analysis with proper consideration of rheology and date of casting. Material properties are adjusted by using CCCC. Episodic numerical predictions can be compared to the equivalent episodic measurements. Unit: Fitness with expected measurements = Prediction/Measurement (%).

**Adequate concrete vibration:** The amount of energy can be related to the vibration of the columns. This vibration can be measured during a casting episode. The total amount of time employed in vibrating a particular column is directly proportional to the energy required. Unit: minutes x column.

### 5.1.4 Productivity Rate

#### *5.1.4.1 About*

Productivity is the most important aspect of any construction project. Therefore, construction companies continue to invest in resources that can boost their productivity. The aspects that can affect construction productivity are labour, material, and technology utilisation. During the construction works it is important how much the production target is far from the actual production. Efficient management of construction resources can lead to higher productivity which can help to achieve cost and time saving.

Construction is a labour-oriented industry. It heavily relies on the skills of its workforce. The labour is the industry's most valuable asset. It is important to improve efficiency of production by improving productivity of labour.

#### *5.1.4.2 Data collection*

The data that can be gathered from the construction site to assess the productivity are photos and video material. In addition, data is collected from various construction aids such as cranes (movements), elevators (movements), deliveries (number and quantity) and resource use (material, space, labour).

#### *5.1.4.3 Calculation & ASHVIN tools contribution*

The main value from 4DV-C tool is derived from using it proactively to visualise the construction sequence. By visually reviewing the project programme from the outset, the process implications of the construction can be highlighted so even when the model is not in use, those implications are known. This then will allow greater interaction at an earlier stage with those who presently don't become involved until much later in the process, which only leads to design re-work once their collective input has been garnered.

There is a critical shortage of experienced construction professionals, which is felt particularly in the planning disciplines, where experience has previously been the only measure used to facilitate planning. The use of 4DV-C shall be extremely useful in educating inexperienced planners, allowing them to meet the required levels of delivery.

4DV-C is used to view 3D stereo images and simulations in actual one-to-one scale. The premise behind the use of this technology is that 4D models can be input into a format more relevant to the site environment and therefore issues identified on a higher-level model can be worked through with those responsible for constructing the area in question, prior to going onsite to do it, in essence a rehearsal of the real installation.

By analysing and identifying a few key areas in the process, communicating that in a way that is understood by all levels of a project team, along with integrating the varied and competing agendas of the contracted specialists, the construction industry will be able to not only reduce the occurrence of delay on projects but also improve the working practices, health and safety record and most importantly, efficiency of their operations, thereby maximising the profit on projects.

Another tool contributing to the determination of productivity rate is CMT tool. The main value from CMT is derived from using it proactively to visualise the construction sequence. By visually reviewing the project programme from the outset, the process implications of the construction can be highlighted so even when the model is not in use, those implications are known. This then will allow greater interaction at an earlier stage with those who presently don't become involved until much later in the process, which only leads to design re-work once their collective input has been garnered. There is a critical shortage of experienced construction professionals, which is felt particularly in the planning disciplines, where experience has previously been the only measure used to facilitate planning. The use of CMT shall be extremely useful in educating inexperienced planners, allowing them to meet the required levels of delivery.

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The DES tool can help to increase productivity on construction sites. Due to the more reliable information about duration of activities, the scheduling and coordination of different activities can be done more precisely. Thus, less idle times occur for equipment and workers. Additionally, the DES tool helps to optimise the allocation of resources and only the equipment and workers, which are needed, are located on construction sites. This is leading to a more efficient construction process. Furthermore, the DES tool enables construction managers to react in (near) real time due to the collected data and the digital twin, if deviations of the planned construction process occur. Hence, the effects of issues on construction site can be reduced.

In general, productivity is the relation of output to the input. Input factors could be the working hours of equipment and workers. As it is aimed to reduce these factors significantly due to the application of the DES tool with the help of collected data, the productivity will be enhanced.

## 5.2 Resource efficiency

### 5.2.1 Waste factor

#### *5.2.1.1 About*

In conjunction with construction work, waste is accumulated continuously. The waste is both taking up space at the construction site which can hinder construction to proceed and is 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.

#### *5.2.1.2 Data collection*

Data could be collected by using trash containers equipped with sensors that notice when trash levels are getting high. Data can also be used as an indicator for if waste is correctly divided according to different categories in the waste containers.

#### *5.2.1.3 Calculation & ASHVIN tools contribution*

Weight of waste per m2. Interval for calculation could be weekly or monthly depending on the pace in which waste is accumulated and the size of containers. Calculation could also be conducted continuously if data is collected daily.

The use of the 4DV-C tool will drastically reduce the paper format of report generation and reduce paper waste during the construction phase. Proper planning for the utilisation of formwork using 4DV-C will lead to decrease of wastages.

### 5.2.2 Number of concurrent trades on site

### 5.2.3 About

On construction site the occurrence of different trades at the same time happens frequently. Each trade requires space for execution of construction works including storage space and safety distance. Sometimes, different trades demand the same or adjacent construction space, which can lead to hindrance among each other. This can lead finally to safety issues, delays in construction execution, higher costs, waste of resources, and overall a low productivity.

#### 5.2.3.1 Data collection

A rough overview can be gained by investigating the schedule of construction works. Additionally, in depth data about the movements of different trades will be collected in a number of ways and saved on an IoT platform. The construction progress will be recorded by photos or videos. A camera will be mounted on site to take time lapse photos of the whole construction site continuously. Additionally, photos or videos will be taken manually to track construction activities. Furthermore, an agile mobile robot can be used to walk remote controlled and to collect data.

Additionally, sensors will be mounted on equipment on construction sites to follow their movements. The WTGAHRS2 is able to detect GPS data to track the exact position of equipment and the related trades. The WT901 WIFI is only able to record movement, acceleration, and so forth, but these data can help as well to track the movement of different trades. For instance, the sensors will be mounted on a crane hook to capture the movement of a pillar. It can be assumed that the pillar is mounted and dismantled on the crane by workers. Hence, precise information about the movement of trades exists.

#### 5.2.3.2 Calculation & ASHVIN tools contribution

Due to the collected data the movement of different trades can be recorded and forecasts about needed space of each trade can be stated. The video and pictures can be investigated manually or by machine learning algorithms, for instance within the DES tool. Thus, it is possible to detect precisely the demanded workspace, storage space, and safety distance.

The sensor data help to track the movements of equipment. The estimation of needed space for complex works such as mounting of pillars can be forecasted much better by the gathered data.

These findings can be incorporated into the DES tool, which simulates the construction processes. The above mentioned collected data deliver valuable input for the DES tool. As more reliable data about the duration of activities will be collected as well, the coordination of construction works by different trades can be coordinated enhanced within the DES tool. Thus, temporal spatial workspace conflicts can be avoided, as different trades will not demand the same workspace at the same time. Additionally, if due to the collected data it can be detected, that deviations of the planned schedule occur - for instance because of weather conditions or machine breakdown – the DES tool can inform to postpone the following activity to prevent the encounter of different trades. Hence, a more efficient usage of resources is possible. Overall, due to the collected data and the usage of the ASHVIN tools the improved coordination of trades can lead to more safe working conditions, to lower productivity losses, lower costs, and a much more resource efficient construction process.

### 5.2.4 Percentage of available space used

#### *5.2.4.1 About*

How space is used decides how time and cost efficient a construction project is. Construction material and machinery in combination with construction workers take up space on the site, which can make it challenging to coordinate work that needs to be done. Another cost in conjunction with construction is parking costs for delivery trucks and manoeuvrability may need to be considered in busy areas with stringent space requirements. Inefficient usage of resources and space due to idle time are leading to higher costs. Therefore, a productive and efficient construction way is leading to lower construction costs.

#### *5.2.4.2 Data collection*

Sensors placed on the construction site and/or cameras to supervise space usage. Data can be used to plan the continued construction work and get a deeper understanding/identify pattern for how space usually is used.

#### *5.2.4.3 Calculation & ASHVIN tools contribution*

The indicator for percentage of available space used is shown in a dashboard along with the 4D model and other indicators showing performance such as equipment use and space use.

Suitable time interval for calculation is weekly to keep track on how construction work is proceeding and if it is following the schedule as planned. This way it is possible to identify congestions or obstacles due to space that is unused or overlooked. The data collection is based on visual analysis that can partly be automated. The measurement interval is typically 15 minutes. The basic formula to calculate the percentage of available space used is available space divided by total space.

### 5.2.5 Utilisation rate of equipment

#### *5.2.5.1 About*

On construction sites there are a multitude of heavy equipment such as cranes or cherry pickers available. Regularly, this equipment is used inefficiently due to high idle times. This leads to a suboptimal allocation of resources as more equipment is delivered to construction sites than actually is needed. Machines are leading to emissions in activity time, but during idle time as well. Additionally, a high amount of equipment finally results in higher costs.

#### *5.2.5.2 Data collection*

Different sensors such as the WT901 WIFI or WTGAHRS2 will be mounted on the equipment on construction sites to track the movement of machines. Data such as GPS, acceleration, and so forth can be collected by the sensors. Thus, information about movement of different equipment can be gathered. For instance, the sensors will be mounted on different positions on a crane such as the hook. In the following, data about the mounting process of pillars will be collected. Hence, by evaluating these data more reliable information about activity and idle time of the crane can be gathered.

Additionally, videos or pictures will be taken of construction works. These recordings can be analysed to find out information about the usage of the equipment on the construction site. On one hand, these data can help to interpret the collected sensor data for determining the separate activities of equipment such as a crane. On the other hand, these records can be evaluated individually to determine the duration of different activities executed by equipment.

#### 5.2.5.3 Calculation & ASHVIN tools contribution

The above mentioned collected data can be evaluated manually or automatically by machine learning algorithms within the DES tool. By evaluation of the collected data more precise information about the activity and idle time of equipment can be gathered. Hence, more reliable information about duration and cycle times of different machines can be gathered in comparison to conventional planning approaches.

In the following, these findings can be used within the DES tool for simulation of construction activities. For instance, the mounting of a pillar by crane will be recorded and analysed. By having more precise forecasts about the cycle time of mounting a pillar, the number of pillars can be multiplied with the average cycle time to predict the duration of these activities. Hence, the planning is much more detailed and precise in comparison to the current applied approach of roughly estimating the number of pillars, which can be mounted per day or week.

The DES tool from Ashvin toolkit can be used in the planning phase to simulate various scenarios of construction works in. Within the tool the results of different construction scenarios – for instance different number of cranes - can be compared according to several PIs such as the utilisation rate of the equipment. The aim is to achieve a high utilisation rate and a low idle time of equipment. Hence, it can be detected more precisely, which equipment is needed on site, and the allocation of resources can be optimised. This is rather a pull process according to lean construction principles to avoid waste of resources.

Furthermore, the DES tool shall enable to track and control the construction sequence in real time due to the collected data. By a more detailed planning it is easier to follow the progress on the construction site. This can enable that construction managers can react in near real time if problems occur on a construction site. If for instance a machine breaks down, the tool can propose to execute other activities, which are using other equipment, to reduce the idle time.

In general, a more efficient utilization of equipment and in the following a more productive construction process can be achieved due to the usage of the collected data within the ASHVIN tools.

In addition, 4DV-C tool can support calculation of utilisation rate of equipment, Figure 8.

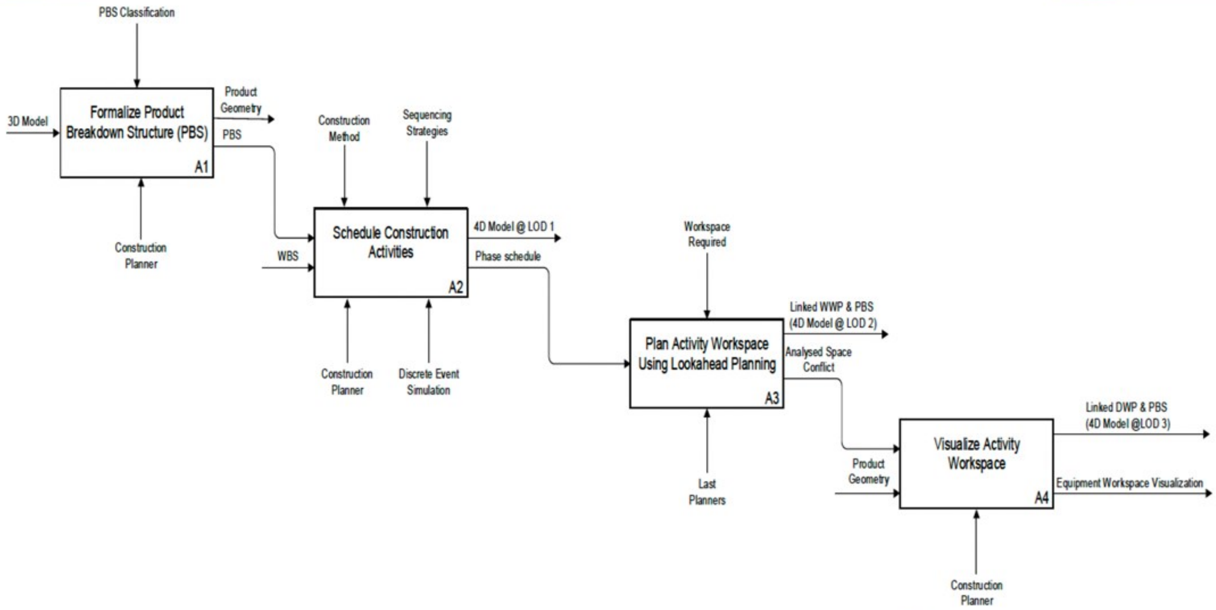


*Figure 8 Context diagram for equipment workspace planning*

## 5.3 Safe construction works

### 5.3.1 Number (and severity) of reported issues related to the accidents on construction site

#### *5.3.1.1 About*

Construction sites are temporary and working conditions change quickly, which makes it challenging to deal with work environment issues. However, injury and death rates are continuously high which have raised awareness within the industry. The main purpose of the investigation of accidents and reporting is to prevent accidents based on the similar previous accidents. Unfortunately, according to Choe et al. (2020), 27% of 135 construction workers did not report their injuries.

#### *5.3.1.2 Data collection*

Data collection is both company records and accident-related issues happening on site. Collected data can be analysed to identify which construction activities that are recurring as high risk and facilitate in planning and making work preparations.

To assess safety performance following data should be collected. Medical treatment injuries, which are injuries requiring medical advice, lost time injuries which are injuries resulted in more sick leave than just the day of injury and the total recordable injuries, which is sum of the medical treatment and the lost time injuries. Furthermore, interviews with the client project leader and the occupational health and safety inspectors will be needed to analyse hazards and dangerous situations, and in addition reports from occupational health and safety inspections (Winge et al., 2019).

##### 5.3.1.3 Calculation & ASHVIN tools contribution

Number and severity of reported accident issues will be shown in a dashboard of ASHVIN platform along with the 4D model and other indicators showing performance such as equipment use and space use. On the dashboard it is possible to visualise accident records in graphs and locations over the site to know when and where they occurred.

### 5.3.2 Safety factor

#### 5.3.2.1 About

Construction site safety is an aspect of construction-related activities concerned with protecting construction site workers and others from death, injury, disease or other health-related risks. Construction is an often hazardous, predominantly land-based activity where site workers may be exposed to various risks. Site risks can include working at height, moving machinery (vehicles, cranes, etc) and materials, power tools and electrical equipment, hazardous substances, plus the effects of excessive noise, dust and vibration. The leading causes of construction site fatalities are falls, electrocutions, crush injuries, and caught-between injuries. Most of the construction incidents are due to “unsafe behaviours” (Nabi et al., 2020).

#### 5.3.2.2 Data collection

Several sensors will be mounted on equipment on construction sites to track the movements. The WTGAHRS2 sensor can record GPS, acceleration, and so forth data to track the precise position of equipment. For instance, the sensor will be mounted on a crane hook to capture the mounting process of a pillar, while the data is stored on an IoT platform.

Furthermore, as pictures and videos of construction site will be taken, the behaviour of workers on construction site can be analysed. Time lapse photos can help to identify the needed workspace of different trades at different times.

#### 5.3.2.3 Calculation and ASHVIN tools contribution

ASHVIN tool 4DV-C has ability to visualise past construction activities based on certain activities tracked by the digital twin platform. SMT tool (extension of 4DV-C tool) gives the possibility to where construction workers, equipment & machineries, and other objects shall be tracked on construction site using game engine platform. These tools support the safety on construction site through:

- Incorporation of historical accident data with a schedule to estimate the fall risk distribution of a project.
- Assessment of the risks for construction activities based on historical data with a network schedule.
- Link quantified pair-wise interaction risks among construction tasks based on experts’ judgments with a schedule.
- Integration of risk data regarding construction trades with activities in a schedule for site safety planning.

Safety aspects will be considered in the DES tool as well. Due to the collected data about equipment movement, coordination of construction sequence can be improved. Due to evaluation the needed workspace for each activity can be seen and precise information about equipment, such as cranes, movements are available. This entails the lifting and rotation of objects, which can fall down. Accordingly, workers' movement and activity execution can be modified to the equipment movement to avoid a hazardous situation where a worker is located under the crane hook during execution. By considering risk situations and trying to minimise hazardous conditions on construction site, it is aimed to achieve a higher safety factor.

### 5.3.3 Strength of structural components (i.e. concrete or steel element).

#### *5.3.3.1 About*

Structural safety is predicted by structural models whose input are the component properties. A certain material strength is guarantee by suppliers. The real strength of the components, even if they tend to be positively biased, is a random variable that deserves consideration. Structural elements can then be characterised more realistically, and their real properties can be visualized and used by stakeholders in due time. Collecting systematically the data of the strength represents a crucial task for the sake of organizing this input. The development of more precise predictions of the structural safety becomes feasible.

#### *5.3.3.2 Data collection*

Concrete cylinders of in-situ casted material are generally managed by quality control agents of the construction site. Systematic development of tests is a standard procedure. Systematic data-structures for subsequent use in a time-dependent digital twin approach are, however, in their infancy.

#### *5.3.3.3 Calculation and ASHVIN tools contribution*

The compressive strength of the components is defined as the applied force during the test (compressive or tensile) divided by its cross-sectional area. Unit: $N/mm^2$.

MatchFem support calculation of strength of the components due to more reliable and precise structural models that adjust the structural safety estimations.

## 5.4 Cost

### 5.4.1 Costs for equipment and workers

#### *5.4.1.1 About*

Costs for equipment and workers take a decisive part within construction costs. Especially, inefficient usage of these resources due to idle time are leading to higher, in fact superfluous, costs. Therefore, a productive and efficient construction way is leading to lower construction costs as the usage of equipment and workers is optimised. By collecting information on how and what equipment is used on the construction site, it is possible to reduce expenses.

#### 5.4.1.2 Data collection

Data about the duration of different activities will be collected. WT901 WIFI or WTGAHRS2 sensors will be mounted on the equipment on construction site to gather data about the movement. For instance, the sensors will be mounted on the hook of a crane. Hence, precise information about the movement is collected. In the following the duration of activities can be found by analysis of the data.

Furthermore, pictures and videos will be taken manually, by fixed cameras or by an agile mobile robot. This information can help to evaluate the collected sensor data. In addition, the pictures and videos can be analysed separately. In general, the collected data help to determine more reliable and precise data about the execution and duration of activities.

The costs for each equipment and workers have to be researched for each country individually by expert interviews with construction managers.

#### 5.4.1.3 Calculation and ASHVIN tools contribution

The DES tool will be used for simulation of construction activities. Due to the collected data and the evaluation of it, more reliable and precise forecasts about duration of activities and in the following about the whole construction process are possible. Additionally, the DES tool helps by planning allocation of resources. This information about the usage of resources helps to calculate the costs for equipment and workers.

The needed time of resources simulated by the DES tool has to be multiplied with the costs for each resource within the DES tool. The function written below can define the costs for resources such as equipment or workers, which are used for fulfilling construction activities on site. The costs of all resources will be summarised in the end. It is aimed to minimise the costs for equipment and workers as much as possible. Within the DES tool different construction execution options are simulated and compared according to PIs such as the costs for equipment and workers.

$$\text{Minimise} \sum_{1}^{n} \quad t_i R_i C_i$$

where:

$t_i$ – Usage time of resource i

$R_i$ – Resource i

$C_i$ – Costs for resource i per time period (hour/day)

### 5.4.2 Mapping of tools vs Performance indicators

Table 5 shows the overview of the Performance Indicators (PIs) and ASHVIN tools and methods that contribute to the improve productivity, resource efficiency and safety construction works.

*Table 5 Overview of Performance Indicators and contributing ASHVIN tools and methods*

| KPIs | Performance Indicators | ASHVIN TOOLS AND METHODS | | | | | |
|---|---|---|---|---|---|---|---|
| | | DES | 4DV-C | SMT | CMT | MATCHFEM | ASHVIN DASHBOARD |
| Productivity | Percentage Plan Complete | | ✔ | | | | |
| | Non-productive working time of professionals | | | | | | ✔ |
| | Component properties | | | | | ✔ | ✔ |
| | Productivity rate | ✔ | ✔ | | ✔ | | |
| Resource efficiency | Waste factor | | ✔ | | | | |
| | Number of concurrent trades on site | ✔ | | | | | |
| | Percentage of available space used | | | | | | ✔ |
| | Utilization rate of equipment | ✔ | ✔ | | | | |
| Safety | Number of reported issues related to the accidents on construction site | | | | | | ✔ |
| | Safety factor | ✔ | ✔ | ✔ | | | |
| | Strength of structural components | | | | | ✔ | |
| Cost | Costs for equipment and workers | ✔ | ✔ | | ✔ | | |

# 6 IMPLEMENTATION ON DEMONSTRATION SITES

The Ashvin platform will be deployed on the demo site using a variety of data sources, including video, scans and sensors.

## 6.1 #4 Logistics hall construction in Germany

The demonstration project is an industrial building located in Rinteln, Germany. The whole building consists of different halls with a total building size of almost 30.000 square meters and has a height of 12 meters. The building will be used to manufacture food packages by state-of-the-art technologies. The construction of the shell consists mainly of prefabricated components according to level 2 of the prefabrication adoption levels.

During construction works several data will be collected. WT901 WIFI and WTGAHRS2 will be mounted on the equipment such as cranes, cherry pickers and so forth to record the movement of the machines. By the usage of these sensors data such as GPS, acceleration, and so forth can be collected. These data enable to simulate the exact movement and usage of the equipment. Additionally, time lapse images are made of construction site continuously.

The collected data can be used for the calculation of several Performance Indicators. In the following three PIs are listed. As the building is constructed by prefabricated components, repetitive processes occur during construction works. One of these repetitive processes is the mounting of pillars by crane. As the sensors are mounted on the crane, information about cycle, activity, and idle time can be gathered. With the help of these data the PI utilisation rate of equipment can be calculated within the DES tool. Finally, it is to be aimed to increase the activity and to reduce the idle time of equipment such as the crane to ensure a more productive construction process. Due to the more reliable forecast of activities on construction site, the allocation of resources can be optimised. Only the needed equipment is located on construction site. In the following, by having more reliable forecasts the calculation of costs for equipment and workers can be estimated. Actually, only movements of equipment will be recorded, but the number of workers is dependent of the amount of equipment and, therefore, the costs for equipment and workers can be calculated due to the more reliable simulation by the DES tool.

Another indicator, which will be investigated on this demonstration site, are the accidents on construction site. Due to the collected data, the exact movement of the equipment is recorded and can be tracked. One example is the movement of a loaded crane. Thus, it is possible to coordinate the movement of workers and equipment, or the execution of construction works enhanced within the DES tool to avoid hazardous situations. Due to the reduction of the number of hazardous situations, the risk for accidents can be reduced significantly.

Table 6 describes relevant Performance Indicators that will be measured for #4 demonstration project.

*Table 6 Performance Indicators related demonstration site #4 Logistics hall construction in Germany*

| Performance Indicators | Implementation process |
|---|---|
| **Productivity Rate** | Productivity rate can be improved due to optimised resource allocation and sequence of construction works. |
| **Waste factor** | Due to prefabrication level 2 and more reliable planning, less waste of material occurs. |
| **Number of concurrent trades on site** | Enhanced coordination of concurrent trades on construction site to achieve more productive and safe construction process. |
| **Percentage of available space used** | Improved organisation of construction space to reduce needed space. |
| **Utilization rate of equipment** | Utilisation rate can be improved due to changes in resource allocation and availability of material. |
| **Number (and severity) of reported issues related to the accidents on construction site** | Due to enhanced coordination of construction works it is aimed to avoid risk situations and finally accidents. |
| **Safety factor** | Avoid the clash of workers and heavy equipment to avoid hazardous situations and accidents. |
| **Costs for equipment and workers** | Due to more reliable planning, costs for equipment and workers can be reduced. |

## 6.2 #5 Kineum office building in Sweden

The Kineum case is a high-rise building located in the city of Gothenburg, Sweden. The project started in 2019 and ends summer 2022. It consists of 30 000 m2, 960-1400 m2/floor and has 27 floors, Figure 9. Once completed it will have a height of 110 meters.

*Figure 9 Construction process of Kineum project in Sweden.*

The main idea of the project is to establish a 4D model that allows for planning and monitoring of resource use, productivity and safety. The 4D model will be analysed in conjunction with data from the site collected by cameras and sensors. One of the data collection methods is based on the application of the Spot robot collecting video spatial data, scanning capabilities etc. In addition, Kineum has prior to the Ashvin project several sensors installed on site that can be utilised to produce performance indicators. Existing sensors measure dust, noise and moisture on construction components and indoor spaces on site and the data they collect can be used to calculate the performance the project has in these areas.

Among the performance indicators that are anticipated to be analysed are usage of space types (workspace, hazardous space, logistic space etc.), usage of resources and several indicators considering health and safety. Indicators for use of space do mainly have to do with observing how spaces on site are utilised in conjunction with ongoing construction activities, while indicators for use of resources are providing insights on how material, equipment and workforce are deployed. Health and safety indicators of interest are considering supervision of hazardous spaces on site, for example ensuring fire distinguisher and other safety equipment are correctly placed and accessible. Collected data will be shown in a dashboard along with the 4D model and other indicators showing performance such as equipment use and space use.

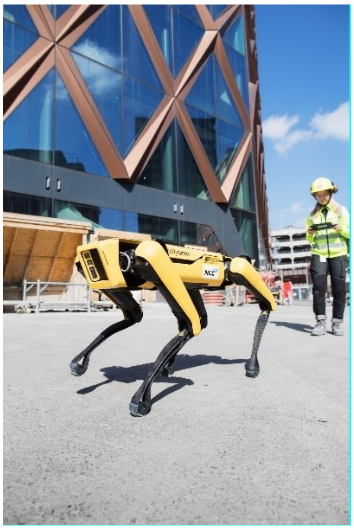

*Figure 10 Mobile robot bought by NCC for implementation on Kineum project.*

Table 7Table 8 describes relevant Performance Indicators that will be measured for #5 demonstration project.

*Table 7 Performance Indicators related demonstration site #5 Kineum office building in Sweden*

| Performance Indicators | Implementation process |
|---|---|
| Component properties | Temperature and humidity sensors are installed |
| Non-productive working time of professionals | Video cameras are installed in some parts of the building to record video material on how workers distribute their time on the construction site. The material can thereafter be analysed and different categories for time allocation can be created. |

| | |
|---|---|
| Waste factor | Waste management |
| Number of concurrent trades on site | Sensors for motion detection are installed in some parts of the building |
| Percentage of available space used | Sensors for motion detection are installed in some parts of the building. Heat maps could be established to indicate space use. |
| Utilisation rate of equipment | Some sensors can be installed on specific machines for time studies |
| Number of reported issues related to the accidents on construction site | Accidents and incidents are reported using a commercially available program and app (Synergi). These data are used for depth investigations. |

## 6.3 #6 Office buildings in Spain

The #6 demonstration project of the ASHVIN project is located in Barcelona, Spain, Figure 11. The construction company is DRAGADOS and one of the structural site managers is BIS, a Barcelona-based structural engineering office which is specialised in the construction of highly technical structures in the building sector that opened the site to Ashvin.

*Figure 11 View from the street ((Universitat Politecnica de Catalunya, 2021)*

The demonstration building is placed in the Sant Marti district in the industrial area of Poblenou (one of the biggest urban regeneration schemes in Europe). The localisation of the construction site in a very dense urban space surrounded by buildings and busy streets, may be a logistical challenge in itself. The specificity of this location can make it difficult to organise the construction facilities and the construction material transport to the site and on the site.

Furthermore, there are challenges associated with the time limitation on the material delivery as well as the space limitations which need to be taken by the machines, equipment, and materials storage.

Among buildings in the current construction site, the target of demo site number six is a building called "Mile". It is a reinforced concrete office building with long-spanned slabs.

*Figure 12 Material storage on the construction site (Universitat Politecnica de Catalunya, 2021)*

On the other hand, from the structural perspective, the construction of this building is dependent on the slab deformation, the limit states of the serviceability, and it has to be constantly controlled.

In this site, the goals are related to monitoring what is happening on the construction site in real time, by using cameras installed on the cranes and gates. Also, sensors for measuring materials characteristics need to be placed in or on top of the components. To summarise, referring to the location and specificity of the project there are several important processes which need to be analysed on this construction site: concrete deliveries and pouring, materials storage, noise level and structural deflection during works. The idea of the project is to establish a 4D model that allows for planning and monitoring of resource use, productivity, and safety. The 4D model will be analysed in conjunction with data from the site collected by cameras and sensors.

Table 8 below describe relevant Performance Indicators that will be measured for #6 demonstration project.

*Table 8 Performance Indicators related to demonstration site #6 Office buildings in Spain*

| Performance Indicators | Implementation process |
|---|---|
| Percentage Plan Complete | Productivity can be improved in the subsequent phases of the project and in the future projects. It is part of the Last Planner® System of Production Control. The main idea is to compare number of the activities completed as planned to the total activities planned. |

| | |
|---|---|
| Non-productive working time of professionals | Video cameras are installed in some parts of the building to record video material on how workers distribute their time on the construction site. The material can thereafter be analysed and different categories for time allocation can be created. |
| Component properties | Productivity can be improved by decrease the unnecessary time of waiting needed. Furthermore, the safety can be improved by assuring the minimal the minimal proper value of the dried mixture. The main idea is to applicate sensors in, or on the concrete slabs. Also, moisture measuring instruments such as a relative humidity meter can be used.<br>When the temperature of the concrete mixture is on the appropriate level the time needed to harden the concrete can be much shorter, which can improve the productivity. The main idea is to use thermometers and other thermal detecting devices or sensors to measure if the materials are in suitable temperature. |
| Percentage of available space used | Improved organisation of construction area to reduce needed space, which can improve the time and cost efficiency of construction project. It is necessary to place sensors and/or cameras on the construction site to supervise and to better understanding how space usually is used. |
| Utilization rate of equipment | Utilization rate can be improved due to changes in resource allocation and availability of material. It is necessary to simulate various scenarios to indicate the best strategy to deploy the construction equipment to the site and to define control strategies based on real-time productivity collected form the sensors. |
| Strength of structural components | The strength of the material must adequately match the values established during the design phase. The cylinder strength is generally obtained in laboratories using certified |

| | |
|---|---|
| | facilities. For the sake of automating the data-gathering process, a mobile application that tracks both collection and cylinder tests procedures will be developed. The process ends with a proper transmission of the obtained results to the Mainflux platform for further use by other stakeholders |

## 6.4 Overview of the Performance Indicators and demonstration projects

Table 9 presents list of Performance Indicators (PIs) that are planned to be measured for three demonstration projects during which construction works will be performed.

*Table 9 Matrix showing relation between demonstration project and related Performance Indicators*

| KPIs | PIs | ASHVIN DEMONSTRATION PROJECT | | |
|---|---|---|---|---|
| | | **#4 Logistics hall construction in Germany** | **#5 Kineum office building in Sweden** | **#6 Office buildings in Spain** |
| Productivity | Percentage Plan Complete | | | ✓ |
| | Non-productive working time of professionals | | ✓ | ✓ |
| | Component properties | | ✓ | ✓ |
| | Productivity Rate | ✓ | | |
| Resource efficiency | Waste factor | ✓ | ✓ | |
| | Number of concurrent trades on site | | ✓ | |
| | Percentage of available space used | ✓ | ✓ | ✓ |
| | Utilization rate of equipment | ✓ | ✓ | ✓ |
| Safety | Number of reported issues related to the accidents on construction site | | ✓ | |
| | Safety factor | ✓ | | |
| | Strength of structural components | | | ✓ |
| Cost | Costs for equipment and workers | ✓ | | |

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