Optimal Construction Management & Production Control

D1.3 – KPIs for evaluating the construction process behaviour

WP1 – Digital Building Twin Process

Version 1.5

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BIM2TWIN Key Facts

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	Partner	Country
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2	TECHNION: ISRAEL INSTITUTE OF TECHNOLOGY	IL
3	UNIVERSITY OF CAMBRIDGE	UK
4	TUM: TECHNISCHE UNIVERSITAET MUENCHEN	DE
5	INRIA: INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE	FR
6	FIRA GROUP OY	FI
7	INTSITE LTD	IL
8	FUNDACION TECNALIA RESEARCH & INNOVATION	ES
9	ACCIONA CONSTRUCCTION SA	ES
10	RUHR-UNIVERSITAET BOCHUM	DE
11	SPADA CONSTRUCTION	FR
12	UNIVERSITA POLITECNICA DELLE MARCHE	IT
13	UNISMART – FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
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16	IDP INGENIERIA Y ARQUITECTURA IBERIA SL	ES
17	AARHUS UNIVERSITET	DK

DISCLAIMER

EXECUTIVE SUMMARY

This document contains the Key Performance Indicator (KPI) framework for evaluating the process behaviour. This KPI framework was consolidated from KPI proposals of partnering construction companies. This framework contains in total 21 separate key performance indicators. These KPIs were divided into three main domains which are execution excellency, quality and safety. The framework was normalized in order to enable comparison between different projects and to facilitate the continuous improvement within a construction project and over the production portfolio. Use of these KPIs enables contractors to optimize their construction flow.

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ABBREVIATIONS

KPI	Key Performance Indicator
WIP	Work in Progress
PPC	Percent Plan Complete
PII	Project Intent Information
PSI	Project Status Information

1 INTRODUCTION

The objective of this deliverable is to provide the technical definition of the Key Performance Indicators (KPI) to measure the behaviour of the construction process and its efficiency. This KPI framework will be used later on this project for providing the situational awareness and quantitative assessment of the construction process performance.

The KPI framework enables to objectively measure if the process is evolving according to the expectations and initial targets. All of the KPIs of this framework have been normalized in order to enable continuous learning. Additionally, the normalization of KPIs will enable a benchmarking mechanism for the construction managers to compare their similar subsequent projects. The KPIs of this framework address the aspects of execution excellency, quality, and safety. Furthermore, the execution excellency have been additionally divided into three sub-domains which are the process efficiency & effectiveness, supply-chain effectiveness and resource efficiency.

2 CORE OF THE DELIVERABLE

As is any business, the overall objective of the construction is to deliver high quality product on time and on budget. Consequently, high process and supply chain reliability and low variability are needed for high throughput, short cycle time and high productivity to coexist. Additionally, due to the fact that construction sites are a high-risk environment for workers, aspects related to the safety are also considered here. Therefore, this key performance indicator (KPI) framework has been divided into three main domains which are execution excellency, quality, and safety.

Key performance indicators related to the execution excellency have been additionally divided into three sub-domains which are the process efficiency & effectiveness, supply-chain effectiveness and resource efficiency. This has been done because even though the resource efficiency is important, the sole optimization of the resources neglect the holistic efficiency of the project. According to Fira's experience, the reason for this is that due to the distributed value chain of the construction, none of the value chain participants have actual dominant contractual decision-making power over the design and execution of the end-product. This occurs even in the strictest contractual models, because project owner, lead designer and general contractor are still dependent of subcontractors bargaining power over the product components and the work sequences of their subassemblies. In this situation, all the participants focus on optimization of their own resources. Consequently, this leads into a situation in which project has been sub-optimized by conflicting interests of the value chain partners. Therefore, the process efficiency & effectiveness and supply-chain effectiveness KPIs are needed in order to balance the performance measurement schema so that overall efficiency of the product delivery is optimized instead of solely focusing on the resources.

The objective of the quality key performance indicators is to provide actionable insight on the project in order to detect any defects early as possible to minimize cost of rework and to ensure the high-quality output. For the construction operations, the quality KPIs enable the continuous improvement during the project. Here the primary focus is to detect any defect that might require deconstruction of any structures. The secondary objective is to minimize the repetition of defects in subsequent work areas in the same work package. With focus on preventive actions and quality assurance, the cost and delays of the rework can be minimized. In addition, with the quality assurance actions the general contractor may improve their operations in the long run by learning from the trade crews. Here the participation of crews is important due to fact they have high amount of tacit knowledge and this should be also used in order to develop better products and work instructions

Finally, safety KPIs aim to proactively identify risks. The primary focus of these is to prevent the occurrence of any safety risks with proper planning and safety onboarding. The secondary focus is to verify that the site personnel will have proper safety measures in place in order to minimize damage of risks which could not be prevented.

2.1 Method

The KPI framework was defined in collaboration with other participants (TECNALIA, ACCIONA, SPADA, IDP) of the Task 1.3 KPIs for assessing the construction process behaviour. The collaboration with the task participants was carried out during workshops series which were divided into two main parts. First of these was the definition of the optimal construction flow and the second was the analysis of the current processes and the best practices related to the KPIs. In this, the focus was on site activities and the building phase of the construction process. Consequently, these KPIs were defined so that they can be applied also during the design phase so that they would represent also the process of creating the Project Intent Information. After the workshop series a draft of the KPI framework was distributed to the participants for their comments. The final KPI framework was written in collaboration with the T1.3 partners and the Technion, who is the technical coordinator of BIM2TWIN project. The Selected content of the workshops are presented in the appendices B, C and D.

Workshop series:

1. T1.3 Kick-off workshop; introduction to the topic & Fira's approach to KPIs
2. Principles of flow by Rafael Sacks
3. Flow in practice by Fira (Appendix B)
4. Digital twin in construction by Rafael Sacks
5. Lessons learned from Diction by Fira
6. KPI setting workshop part 1: process (Appendix C)
7. KPI setting workshop part 2: partners proposal for KPIs (Appendix D)

2.2 Results

Execution excellency KPIs (figure 1) have been divided into three main categories which are process efficiency & effectiveness, supply chain effectiveness and resource efficiency. Process efficiency & effectiveness KPIs for measuring the process flow are cycle time, throughput (volume), and work in progress. First, the **cycle time** measures the time required to complete a cycle of a process (Hopp & Spearman, 2011). Here, the process could be specified contextually enabling the normalization of the KPI. In practice, general contractor is able to follow the cycle time of the process of which they are interested in. For instance, the observed process could be as high level as from frame installation to internal delivery of an apartment or as detailed as cycle time of specific component installation.

Secondly, the **throughput** measures the number of units produced by a specific manufacturing process during a specified period (Hopp & Spearman, 2011). Similarly, to the cycle time, the units are specified contextually in order to enable the normalization of the KPI. In other words, the throughput can be used to analyze progression of any component installation on site. For instance, during the foundation work the throughput rate of the reinforcement might be expressed as weight of steel installed during the day. For the building's structural framework, high-level throughput measurement could be how many floors/stories are built per week or month. Additionally, a more detailed throughput KPI for the framework would be to measure the square meters of the slabs done per day, length of walls done per day or quantity of precast concrete components installed per day.

Finally, the **work in progress** (WIP) represents the number of unfinished units in specific moment of time (Pound et al. 2014). In order to facilitate continuous flow, the WIP amount for a trade should be minimized. This means that each subcontractor should only have specific amount of work areas as WIP throughout the project. Optimal WIP per trade should reflect the content of the work package, balanced throughput, and amount of work force. Simplified, subcontractor should have only as many work areas as WIP as they can perform value adding work simultaneously. In other words, subcontractors should not have work areas as work in progress if they are not working on those work areas. This is because unfinished tasks require extra effort on project management due to the inability to proceed with optimal task sequence and they also on some occasions prevent completion of adjacent tasks.

In order to deliver the project on time, the slack between different process phases should be minimized. Therefore, the process flow variability should also be measured and therefore additional KPIs should be included for measuring the process efficiency, including **cycle time variability and**

throughput variability. (Modig & Åhlström, 2012) These specific variability KPIs enable early identification of possible errors in the production. Consequently, they enhance continuous improvement and capability to perform root cause analyses so that defect rate per trade and work package can be decreased during the project and from project to project.

The supply chain effectiveness KPIs represent the supply chain reliability and responsiveness. The reliability KPIs are **order fulfillment timeliness** and **order fulfillment quality** and the responsiveness KPI is the **order fulfillment cycle time** (cycle time from order to delivery). The order fulfillment timeliness measures the number of on-time deliveries out of total deliveries. The order fulfillment quality measures the number of zero-defect deliveries out of total deliveries. The zero-defect deliveries refer to deliveries that contain all the components that were ordered and are intact.

Resource efficiency KPIs contain both worker's efficiency and equipment's efficiency. These KPIs focus on the capacity and utilization rate of resources. Additionally, the planning capability of the resources is considered. For the workforce, the main KPI is the capacity. Capacity threshold values are set for tasks and trades, specifically to reflect the industry standard workforce capacity for different types of tasks. This will be further refined with actual data collected from other projects and that specific project in construction of which is followed with this KPI. **Workforce capacity** is measured according to the time used per unit of production. The actual data of this is compared to the historical data and to project specific objective and planned workforce capacity threshold values to determine whether the actual capacity reasonable level. In practice, the workforce capacity can be measured for example as how many working hours was needed per kg of steel, square meters of formwork or linear meters of wall. Additionally, the **workforce utilization rate** has to be inspected. This is because, the workforce utilization rate indicates the amount they are able to perform value-adding work. Consequently, it is necessary to measure waste in the process referring to unnecessary movement, waiting and rework among others.

For the equipment the main KPI is the **utilization rate**. Equipment utilization rate represents the ratio of the time when equipment was used compared to the total time of the equipment on site. The equipment target utilization rate has to be set specifically. For large equipment, the actual time used can be collected for example from the integrated system/computer of the machine (if data transfer method exists), sensors installed to a machine or remotely with video analytics. For smaller equipment meaning anything that is moved by workers, including but not limited to handheld machines, the actual data can be generated manually according to the worker reports, semi-automatically based on equipment location (RFID or BLE tag) , automatically based on data generated by the equipment itself or external sensors. The actualized equipment utilization rate is compared to target equipment utilization rate. Consequently, this information can be used for example to determine if some rental equipment should return to suppliers.

Process efficiency & effectiveness and resource efficiency KPIs are related to the additional indirect effectiveness KPI which is the **percent plan complete (PPC)**. The PPC reflects the site management capability to perform production planning especially on short lookahead time periods such as day and week. PPC represents the percentual number of planned tasks fully complete in each time period. By using the PPC, the project management may improve its lookahead planning to make this more realistic. Consequently, the implementation of the PPC could enhance the overall situational awareness of the construction project and support the project delivery. (Ballard, 1999)

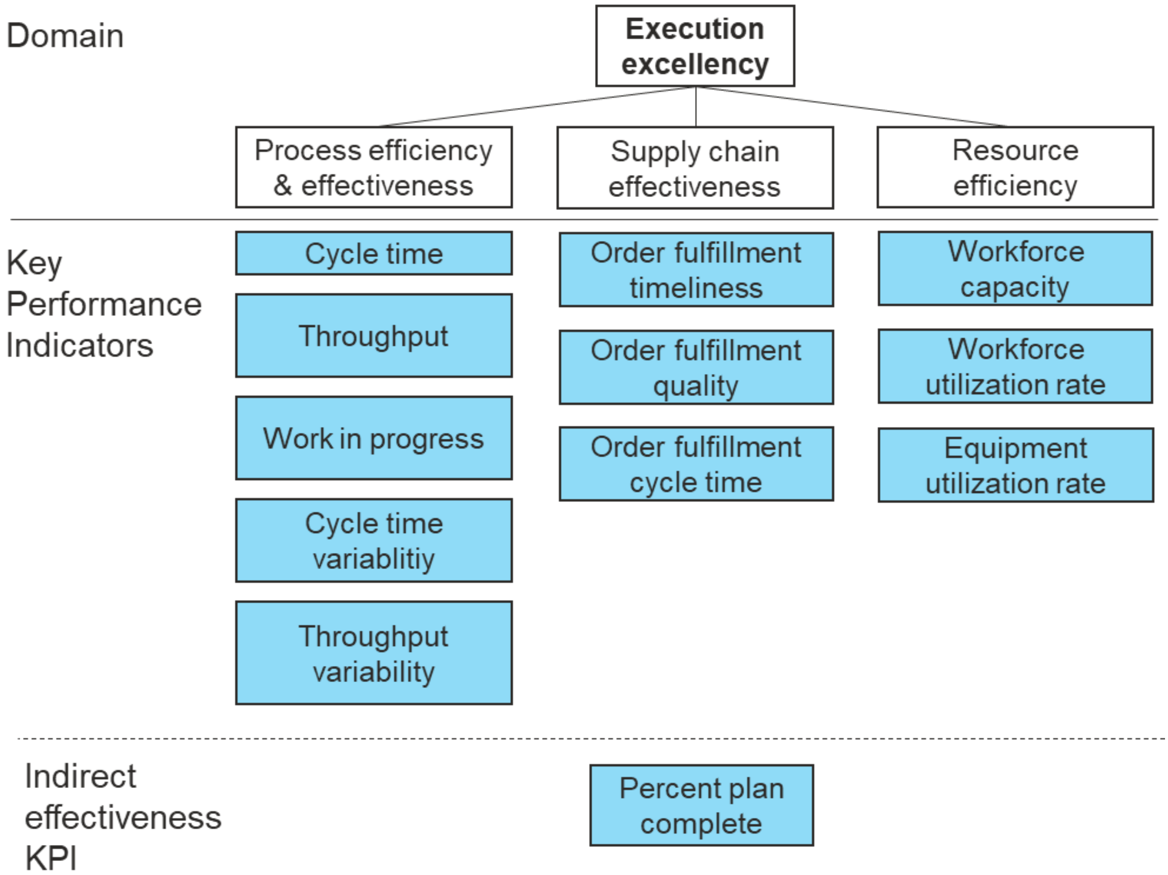

Figure 1 Execution excellency KPIs

Quality management is an essential part of construction project. Ideally quality management is closely integrated to tasks management processes. In this way, construction companies pursue to execute quality assurance which objective is to avoid defects in production. Additionally, quality control procedures are required in order to achieve capability to identify and fix defects. (Arditi & Gunaydin, 1997)

Primary KPIs for quality management are the number of **defects per work package** and **zero-defect executions of total executions** (figure 2). Here, the relative frequency of the defect count per work package should descend whereas the relative frequency of the zero-defect executions should increase during the project. Additionally, the frequency **of work package delays** due to unfixed defect should be observed as one of the quality management KPIs. Here the defects have to be categorized according to their importance. Certain defects have high importance and they should be solved immediately so that work could continue. For example, defects in technical and structural components that risk their proper functionality belong to this category. Other defects belong to medium importance category in which it is enough to solve them as the last task(s) of the work package in that work area. Any work related to technical subassemblies that will be covered with a surface belong to this category, for example the moisture insulation in bathroom and electric wiring in drywalls. Finally, third category would be defects with low importance. These are defects that can be solved as last task(s) of the subcontract. These are for example easily replaceable parts of kitchen cabinets and aesthetic dents in the painting.

Secondary quality management KPIs are related to construction process quality and quality management efficiency. The construction quality of construction process can be inspected by counting the **fraction of zero-defect work area handover** out of all work area handover. This KPI informs reactively how successfully the work prerequisites have been fulfilled. Meaning that have the adjacent tasks been completed in time and quality, is the work area free of other tasks, has the correct material arrived, are the designs ready and shared to workers, are the conditions in place, does the subcontractor have enough skilled workers, do the workers have proper equipment and finally do the workers know the task sequence and process of their work package. Quality assurance efficiency can be analyzed by inspecting the number of defects identified and fixed by the work group during their task execution on that work area out of the total amount of defect in that work area. In other words, this KPI would tell whether the workers are capable of quality assurance during their work or did someone else have to put effort on the quality control related to that specific work package.

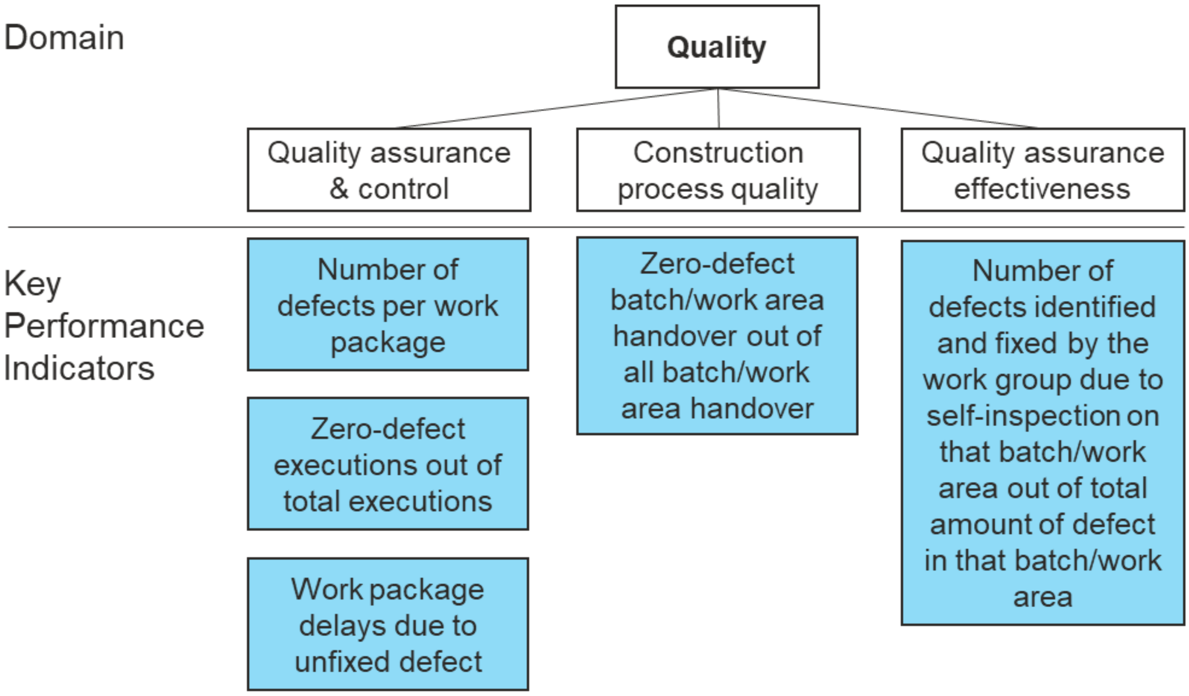

Figure 2 Quality KPIs

Safety KPIs (figure 3) inform that the safety management on site is at the target level to meet the external and internal safety requirements. Here, the external requirements refer to safety level set by the local authorities or the client and internal requirements refer to safety level set by the contractors and suppliers in their production and delivery. Therefore, the primary KPI for the safety is the **site safety level** which is inspected commonly by the general contractor or a specified safety coordinator on weekly basis. This site safety level is the frequency of correct safety observations out of total safety observation during the site safety level measurement round around the site. Separate entities can be measured on their own. These entities can be for example, use of safety gear by workers, scaffolding, falling protection, machines and other equipment, electricity, cleanliness, and dust on site. (OHS Administration in Finland, 2021) Additionally, the site safety level information can be refined with the additional safety observations that are reported occasionally in between the specific site safety level analysis round. The secondary safety KPI is the **risk assessment completion level**. Here the risk assessment refers to a task which is done together by general contractor's foreman and subcontractor workers as part of the site onboarding and subcontract kick-off meeting. In the risk assessment the participants inspect the task sequence of their work package(s), identify risks related to different tasks and agree on safety measures to prevent the risks.

Additional safety KPIs are **time required to solve a defect** and **accident frequency**. Target solving times for the defects should be matched according to the importance of the defect. For example, anything related to falling protection should be fixed immediately whereas nearly full trash bin can be emptied within few days. Accident frequency is counted by dividing all of the accident that lead to disablement of over one workday by one million working hours. In Finland the overall accident frequency of the construction industry has been ranging from 30 to 20 in 2010-2020 (CFCI, 2021).

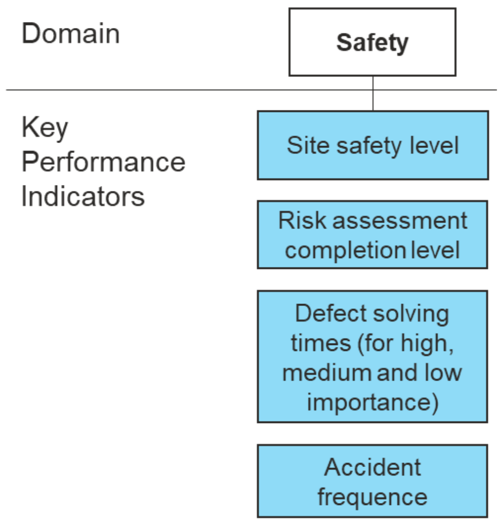

Figure 3 Safety KPIs

3 CONCLUSION

The objective of this KPI framework was to define the Key Performance Indicators to measure the efficiency of the construction process. The KPIs presented in this framework enable construction stakeholders to objectively measure progress of a construction project.

The KPI framework addressed both of the main construction process phases, design and build. However, the focus of this framework was on the site activities and the build phase of the construction process. This approach was selected because onsite execution is crucial mainly because in the end the client buys the product and not the design and the build phase is that where the product is manufactured. Nevertheless, KPIs from the Execution Excellency and Quality domains can be applied also for the design phase due to their normalized definitions. The KPI identification was done with an additional target to identify also leading indicator and not just lagging indicators. The purpose of this was to identify KPIs that would also enable proactive control of the production and problem solving so that occurrence of the roadblocks and consequently schedule delays would be minimized. However, proper division to leading and lagging indicators requires further research.

In the design phase the process performance is measured in relation to the Project Intent Information (PII). Similarly, in the build phase the process performance in measured in relation to the Project Status Information (PSI). The Project Intent Information contains all of the information related to the future state of the building design and construction plans. Consequently, the PII represents the *as-designed* and *as-planned* information of the project. The Project Status Information contains all of the information related to the past state of the building. In other words, the PSI represents the *as-built* and *as-performed* information of the project. (Sacks et al., 2020). The objective of the PII is to contain all information about what should occur in the project and ultimately at the work areas meaning in practice that what to install, when and by whom. In other words, the PII corresponds directly to the capability to perform the project in quality, on time and in budget due to fact that it contains the information to manage the construction. Therefore, the completeness of the Project Intent Information could act as additional leading key performance indicator for the Execution Excellency KPI domain.

As a result of this deliverable, in total 21 KPIs were identified. The KPI framework has been divided into three main domains which are Execution Excellency, Quality and Safety. Most of the KPIs (12) considered in the framework belong to the Execution Excellency and its subdomains which were 'process efficiency & effectiveness', 'supply chain effectiveness' and 'resource efficiency'. The process efficiency & effectiveness KPIs are the main indicators of the construction process progression. Supply chain effectiveness subdomain was included in order to emphasize the importance of suppliers and subcontractors' deliveries for the construction flow. In addition, the resource efficiency supports the enablement of optimal construction flow with indicator related to capacity and utilization rates. The quality domain contains five KPIs. These include both quality assurance and quality control. The inclusion of the quality assurance was done so that construction stakeholders could proactively analyze their performance in terms of the quality. Finally, the safety domain contains four KPIs. One of these acts fully as leading indicators of the safety, risk assessment completion level.

Overall, by observing the production with the proposed KPI framework the general contractors are able to optimize their construction flow and improve their productivity in each project and in the long run.

APPENDIX A: LITERATURE

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APPENDIX B: WORKSHOP 3 FLOW IN PRACTICE

Construction process of a subcontract for achieving optimal construction flow

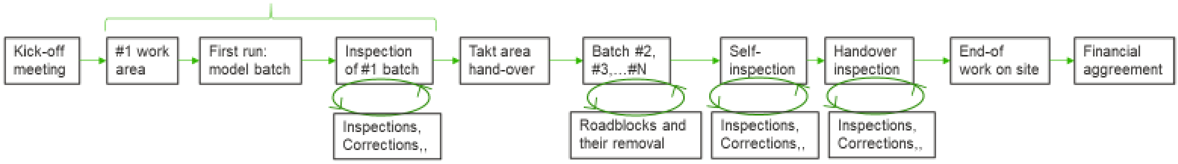
That supports

1. Reduction of the making-do[1] and task diminishment[2]
2. Handling of the defects in design and improvisation
3. Understanding together the definition of done

First batch and inspection is vital for the construction flow for two reasons:

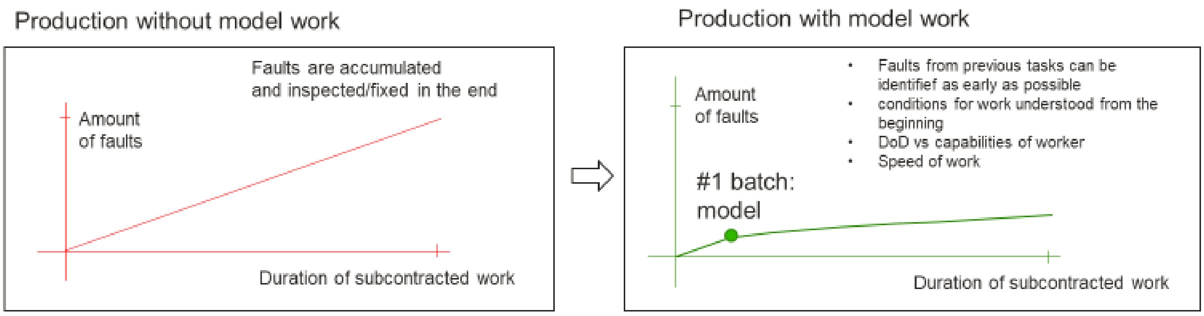
1) defects and collisions in design

2) finishing quality

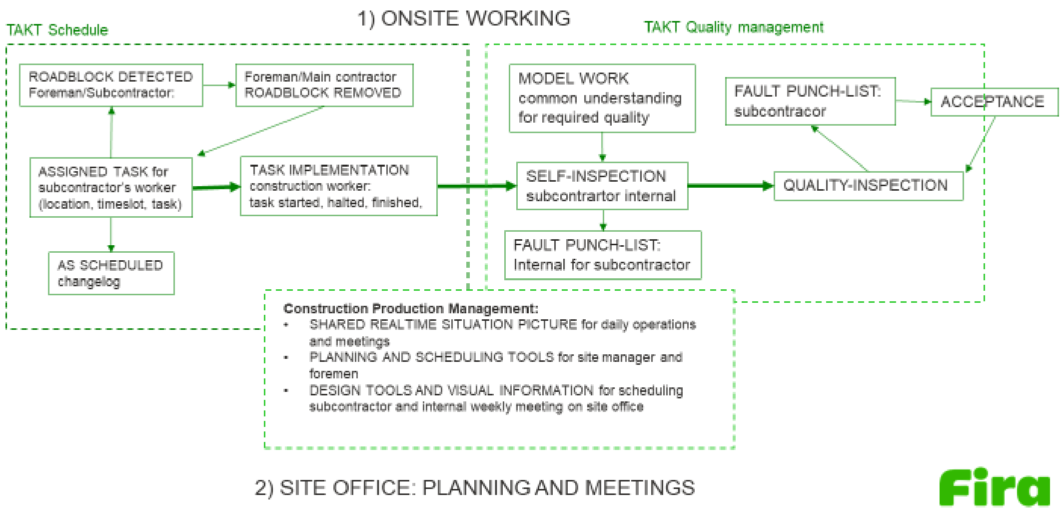


1) Bølviken, Trond, John Rooke, and Lauri Koskela. "The Wastes of production in construction–A TFV based taxonomy." Proc. 22nd Ann. Conf. of the Int'l Group for Lean Construction. 2014.
2) Patton, John R. *Task diminishment: construction value loss due to sub-optimal task execution*. Diss. Indiana State University, 2013.

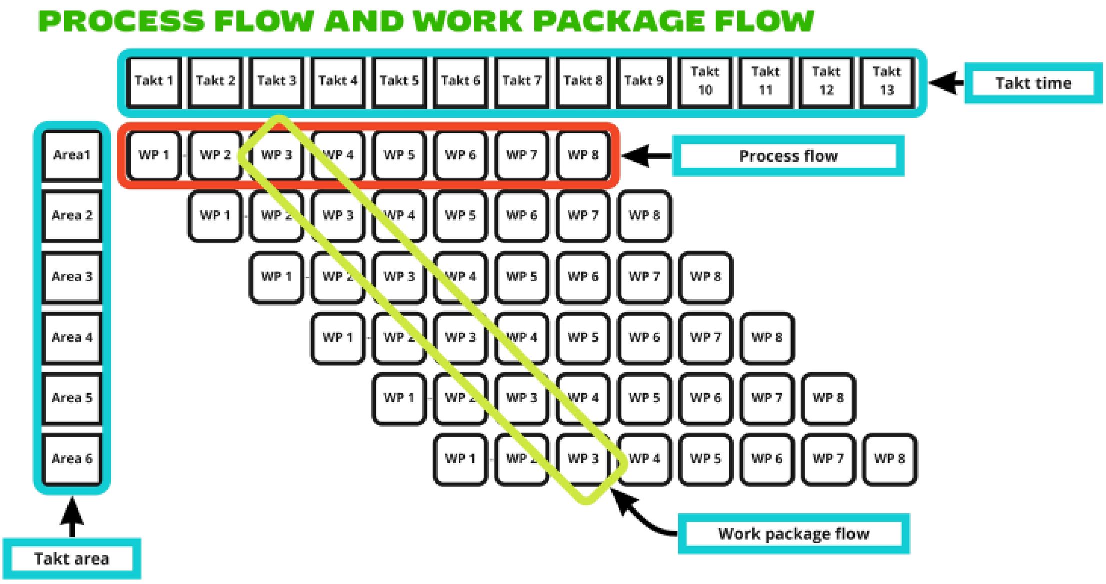
Expected result for first batch / work area model work

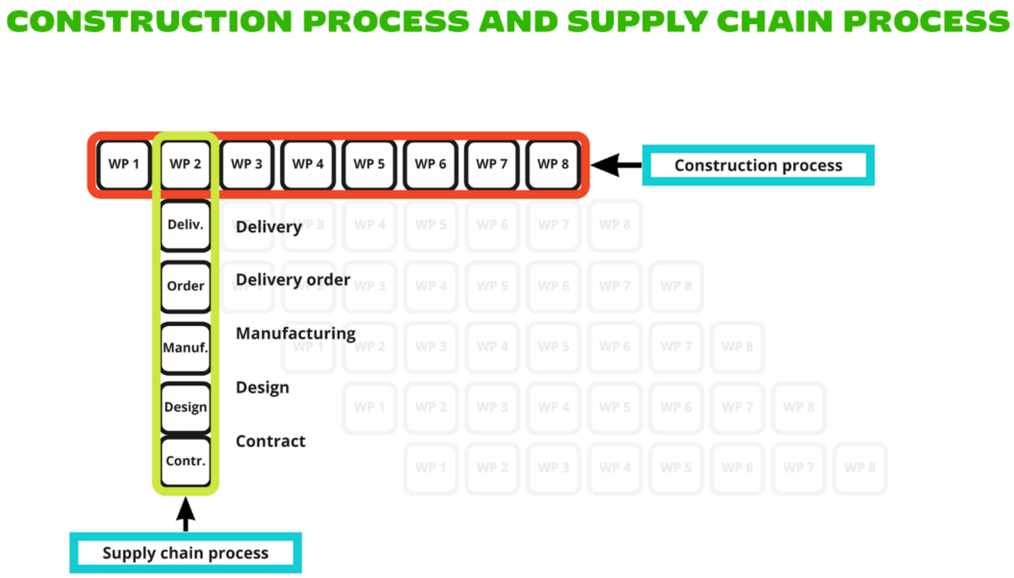


Relation between schedule and quality management onsite



Appendix C: Workshop 6, Construction flow: process flow, work package flow and supply chain process





APPENDIX D: WORKSHOP 7 PARTNER PROPOSALS FOR KPI FRAMEWORK

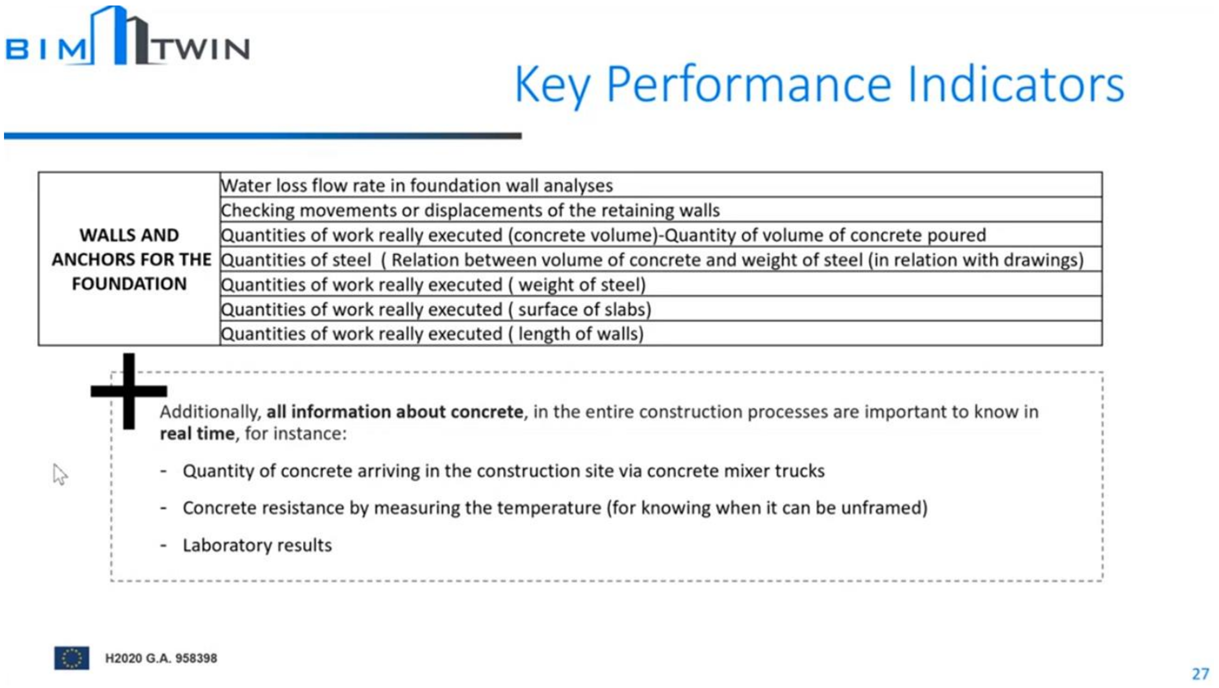


Figure 4 Acciona proposal for KPIs

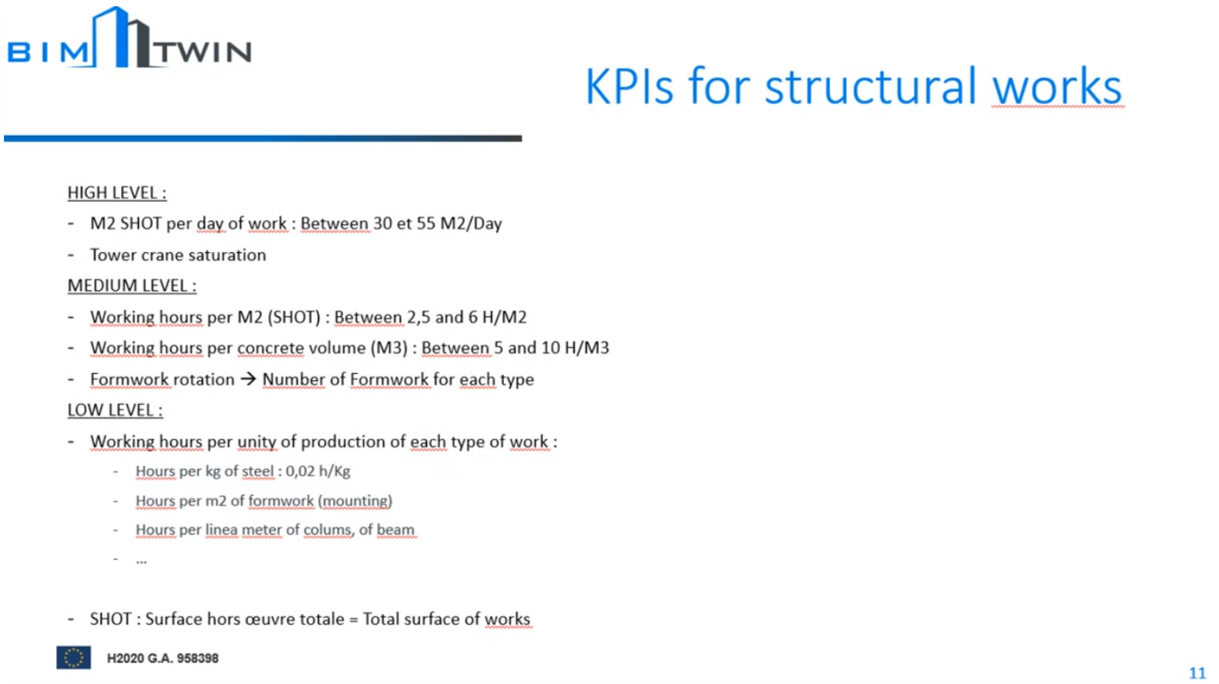


Figure 5 Spada proposal for KPIs

FIRA KPI'S FOR CONSTRUCTION FLOW

Process KPI's

- Process flow
  - Cycle time
  - Throughput
  - Work in process
- Process flow variability
  - Cycle time variability
  - Throughput variability
- Process quality
  - Fulfillment of prerequisites of work (zero defect work area hand overs / all work area hand overs)
  - Zero defect work packages (zero defect work packages / all work packages)
  - Number of defects per work package

Supply chain KPI's

- Supply chain reliability
  - Order fulfillment timeliness (on time deliveries / all deliveries)
  - Order fulfillment quality (zero defect deliveries / all deliveries)
- Supply chain responsiveness
  - Order fullfillment cycle time (cycle time from order to delivery)

Fira

Figure 6 Fira proposal for KPIs