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CONTINUOUS IMPROVEMENT OF TAKT PRODUCTION WITH DATA-DRIVEN KNOWLEDGE MANAGEMENT APPROACH

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ABSTRACT

This study investigates how data-based continuous improvement could be applied in construction projects utilizing takt production. The purpose is to define a process model that will guide how such a continuous improvement system can be created in an organization utilizing takt production methods, and how the system can then be improved.

This research follows design science approach to highlight the practicality of the solution. Research consists of diagnosis, process model creation, validation of the process model, discussion, and conclusion. Diagnosis is performed with a literature review and empirical research, including interviews and observations of current practices in a case company. Validation is performed by collecting external feedback and by organizing internal interviews.

The findings indicate that the created process model provides a system that can be used to improve the takt production process with data, and that the process can be supported by also handling tacit knowledge. A defined learning system will help in tackling the current barriers facing the construction industry related to inefficient data processing and unclear knowledge management. As the system utilizes the terminology and theory of takt production, it is proposed that the system can be expanded to other projects and construction functions with further research.

KEYWORDS

Lean construction, takt planning, continuous improvement, knowledge management.

INTRODUCTION

The ideology and actions of continuous improvement have already been seen beneficial in several other fields, such as shipbuilding (Liker and Lamb, 2001); it could be similarly assumed that continuous improvement could be implemented in the construction industry as both the construction and shipbuilding industries are mostly project-based, local, and highly volatile (Segerstedt and Olofsson, 2010). However, improving the operations and

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productivity of the construction field in general has faced an issue: companies are very independent on their development actions (Henderson et al., 2013.) Additionally, a case-by-case approach to plan and control projects often ignores the lessons learned in earlier projects, which limits the continuous improvement of construction projects (Lehtovaara et al., 2020). This, combined with the habit of mostly tackling issues when they arise, restricts the development of knowledge management in construction compared to other industries (Ruikar et al., 2007).

Continuous improvement can be supported by having structured information and an efficient production system. However, while data is widely collected in construction projects, the inadequate quality of this data restrict its usage in continuous improvement (Bilal et al., 2016). Henderson et al. (2013) state that creating a system that effectively collects and implements lessons learned in past projects helps organizations gain increasing benefits from learning. Structured information and production systems in construction could potentially be achieved with takt production (Dlouhy et al., 2016; Binninger et al., 2016).

Takt production is a well-functioning method that improves the production phase of construction projects in terms of productivity and project lead time (Frandson et al., 2013; Dlouhy et al., 2016; Lehtovaara et al., 2019). Takt production provides definitions and guidelines to describe unique construction projects in a systematic manner (Dlouhy et al., 2016; Binninger et al., 2016), which facilitates the collection and addressment of data and information systematically throughout projects. The application of the learning system described by Henderson et al. (2013) could potentially enable benefits from takt production to reliably increase over time in an organization.

Based on the aforementioned research gap, the goal of this paper is to create a data-based process model for the continuous improvement of takt production. the process model is approached with a design science approach to combine practical knowledge into theory.

RESEARCH DESIGN

This study follows a design science approach and aims to find a theory-based solution to solve a practical issue (Holmström et al., 2009). According to Holmström et al. (2009), the design science approach is formed by four steps: 1) diagnosis to define the issue, 2) development of a solution, 3) testing and validating the solutions, and 4) generalization of the defined solution and justification of the used theory. To emphasize the practicality of the created solution, this study implements an action research approach to support the design science steps. In action research, practice and theory are combined throughout the study to steer the solution with continuous reflection regarding the decisions made during the research process (Azhar et al., 2010). A practical view is brought to this study by creating a process model in the context of an infrastructure segment of a large Finnish case company. The research steps of this study are presented in Figure 1.

Diagnosis is performed through a literature review and empirical research. The literature review focuses on takt production, which is supported with lean construction and knowledge management. The empirical research focuses on observing operations and interviewing personnel of the case company. Company interviews are semi-structured and include people from parking center projects and specialists working in the infrastructure segment and corporation. The findings of the interviews are placed in tables to categorize the responses, which are then induced into general conclusions to present the main results of the interviews. The interviews are then accompanied by investigation of data handling system, which is used to collect and address the information of projects. The findings and conclusions of these steps are developed into a process model that is placed into the company's project business, especially the construction of on earth parking centers. Creation of the process model is performed by listing the development propositions found during the empirical research and solving them by adapting the methods presented in the literature review. The parking center is a suitable case example due to the company's experience in takt production on that specific product. Utilizing the experience of implementing takt production in this specific product type serves the needs of the company, while simultaneously providing an opportunity to learn about the continuous improvement of takt production in general, to later excel in a wider scope.

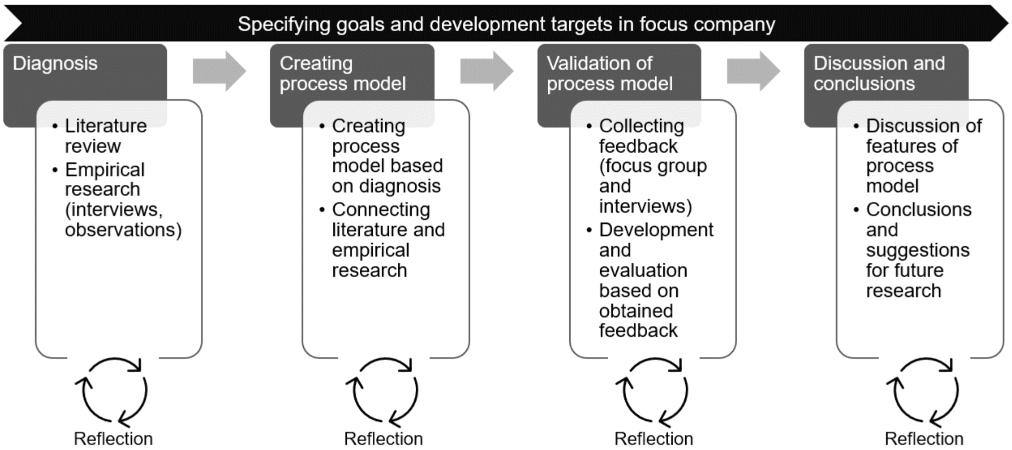

Figure 1: Structure of the research steps.

The testing and further development of the process model is performed by interviewing personnel of the case company (internal validation) and with an external focus group meeting with representatives from 20 architecture, engineering, and construction companies seeking feedback regarding the solution and its suitability. The feedback is obtained as responses to questionnaires, and those responses are then categorized to identify the required modifications to the process model to ensure successful implementation. Finally, the process model is evaluated by considering its potential in a variety of construction product types, and other functions of construction operations, to confirm its practical value. In discussion, scientific contribution is evaluated by examining how presented theories are applied in the proposed process model. The conclusions and suggestions for future research are presented last to ensure practicality and to expand the scope of the model. The suggestions account for the limitation that there is no test case project in this research to validate the success of practical implementation of the created process model.

DIAGNOSIS

FROM LEAN CONSTRUCTION TO TAKT PRODUCTION

Takt production is based on lean thinking, where the main target is to optimize the value creation of production while reducing waste (Koskela, 2000; Liker, 2003; Binninger et al., 2016; Linnik et al., 2013). Optimization is performed by pursuing perfection in production planning and operations (Womack et al., 2007). Improvement of production focuses on the flow of the entire production chain, which can be pursued with an even work pace that is defined by customer requirements to meet the deadlines (Liker, 2003).

Plans will always face deflections during production execution (Koskela, 2000), leading to the need of an effective production control system. One method used to control production in construction is the Last Planner System™, which highlights the need for a detailed short-term production plan that helps detect deflections before they lead to delays (Ballard, 2000). Having a detailed production plan with requirements for performing upcoming work will cure the issue of solving deflections reactively (Ballard, 2000).

Implementing a lean ideology has also led to the consideration of the implementation of continuous improvement and standardization in construction processes. A standardized production process functions as a starting point for continuous improvement (Liker, 2003) and reduces variations in the process (Koskela, 2000). By encouraging innovation, the production process can also be increasingly improved, which can lead to a more optimized standard process via trial and error (Liker, 2003).

To adapt lean methods and ideologies, various studies have developed a takt planning and production system to describe the construction process and products in a creative manner (Linnik et al., 2013; Binninger et al., 2016; Dlouhy et al., 2016). Takt production presents the construction process in a new manner, one that includes work packages, work sequences, and takt areas (Haghsheno et al., 2016; Dlouhy et al., 2016). Work packages and sequences depict the production process in a manner that allows for the transfer of deeper knowledge between projects, as more information can be easily tied to certain tasks while adapting to customer requirements (Dlouhy et al., 2016).

Takt production enables an even workflow with the help of work packages that are planned for closely aligned lengths (Linnik et al., 2013). By emphasizing process flow instead of solely maximizing labor efficiency, takt production allows for the development of overall flow, particularly when production flow is supported with the well-planned use of buffers, especially favoring capacity buffers instead of large time and space buffers (Lehtovaara et al., 2021).

KNOWLEDGE MANAGEMENT IN TAKT PRODUCTION

Knowledge management highlights the systematic management of knowledge and data leading to knowledge-based improvement. According to Lehtovaara et al. (2019), the learning process of a project-based organization can be described with three concrete steps: 1) acquisition of the information and data created in projects, 2) filtering and analyzing the collected information and data, and 3) storing and implementing the collected information and data. Implementing these three steps in construction can lead to increased learning and development in individual projects. However, the collected data from construction projects has been problematic due to a lack of cohesion and quality (Bilal et al., 2016). Therefore, there is a need to define a process that guides how construction project data should be collected to create knowledge.

Blackler (1995) proposes that there are five types of knowledge (embrained, embodied, encultured, embedded, and encoded) with different features that affect how they should be addressed to gain benefits. Following this categorization there is a need for a method to structure information in construction so that knowledge is not lost during the learning process. In this study, information is structured by applying the methods and terms of takt production.

As it is central in takt production to standardize the production process (Dlouhy et al., 2016), it is also possible to utilize the standardized process to achieve continuous improvement by adding new information to it with lean principles (Binninger et al., 2016; Liker, 2003). Earlier, the problem with the standardized construction process has been the fact that unique features of projects and the information collected therein could not be directly utilized in another project. One possible solution to tackle this problem is the use of takt production's work packages, which tie explicit knowledge (Nonaka and Takeuchi, 1995) to standard units, which can be applied to various projects.

If explicit knowledge can be processed with methods of takt production, there is still a need to find a solution regarding the management of tacit knowledge (Nonaka and Takeuchi, 1995) alongside takt production, as tacit knowledge is found to be remarkably important in construction (Carrillo and Chinowsky, 2006).

INVESTIGATION OF THE CURRENT STATE OF TAKT PRODUCTION AND LEARNING IN A CASE COMPANY

The target of diagnosing the current state of the case company was to identify how the process model can adapt to fit into the specific needs of the company. At the start of this study, the infrastructure segment of the company had run a couple parking center projects with takt production methods. The execution relied on expertise of a takt specialist, who was responsible for creating and supporting the new production system. The following three observations were found to be successful during the diagnosis of the current takt production implementation:

1. Takt production helped the task crews work in more locations simultaneously.
2. The production plan can be prepared further ahead, which helped detect deflections before they occurred.
3. Takt production provided project personnel with an experience of more comprehensive control over daily work on site.

As a result, the implementation of takt production led to less remarkable schedule overruns in tasks during project execution. This has come as a by-product when project personnel understand that takt production seeks to improve the control of production leading to less deflections, not that the takt schedule itself would lead to actual benefits.

However, during interviews and observations, a few drawbacks were noticed that currently limit the continuous improvement of takt production. First, the experiences are not wide enough to form a standardized production process that fits into every takt project in a certain segment. It was noticed that there is a need to simplify construction methods in a manner that narrows down the variation between the execution of projects to speed up the standardization process. When there are more projects performed with similar construction methods and features, the organization can develop work package and sequence structures, as proposed by Dlouhy et al. (2016), which will then begin to develop a standardized construction process. After formation of a standardized construction process, improving information content tied to its work packages functions as a basis for continuous improvement of takt production.

To develop work packages and sequences, it is important that the organization collects data and information accordingly, so that gained knowledge can be easily connected to the actual construction actions performed on site. According to interviews and Bilal et al. (2016), construction data is currently collected through various methods and systems that lead to fragmentation and difficulty in the automatization of data processing. Consequently, when handling data and information requires vast amounts of manual work, there are no resources to perform analysis and learning during or after a project when needed. When the data collection system is tied to structures of takt production, however, it becomes evident what information is beneficial to the actual construction operation, which was mentioned as being important in the interviews. This can help judge, in the future, what information organization needs to simultaneously serve the needs of sites and management, leading to a learning system with less non-necessary work.

When tacit knowledge is concerned, a learning system cannot entirely rely on the collection of data and written information directly from projects. There is a need for a defined system pertaining to how feedback is collected and how innovation is ensured. Currently, innovation has mostly relied on active individuals to mention their ideas, which implies that there are numerous ideas left unshared. Commonly, in construction, various post-project reviews are used to collect lessons learned from recent projects and their personnel; however, the benefits from these reviews are limited by the lack of time that key personnel have and the lack of a systematic process to address content (Carrillo, 2011).

Construction projects always consider their many stakeholders, so it is relevant to also include subcontractors in their consideration when the main contractor is willing to implement a new production system. A challenge faced with takt production, according to interviews, is that it is a new system for many subcontractors, which often leads to resistance, arguing that the system is unsuitable for their tasks. However, according to interviews, this thought has proved to be faulty, and conversely, implementing takt into new tasks has led to subcontractors finding new benefits and appreciating the accurate production plans that perform well in practice. Still, contracts that may be conflicted with the takt production system are currently limiting subcontractors' benefits regarding the implementation of takt production (Lehtovaara et al., 2019). For example, instalments may be aligned so that working against takt production plans may benefit subcontractors' cash flow, which can lead to issues with total flow at the work site.

To conclude, there are four topics to be covered in the process model to ensure the continuous improvement of takt production:

1. There is yet no standardized production process to be improved systematically.
2. Data collection must be aligned with takt production structure, which simultaneously provides the required information to site operations and management.
3. The learning process is not clearly delineated and improvement relies on active individuals.
4. Subcontractors' contracts need to be aligned so that their interests meet the requirements of takt production.

PROCESS MODEL FOR THE CONTINUOUS IMPROVEMENT OF TAKT PRODUCTION

The continuous improvement of takt production is guided by a cyclic process model (Figure 2), which describes and supports institutionalized knowledge sharing and functions as a clear guide on how to address data and tacit knowledge as a part of the learning process. The process model proposes that, in the production phase, data is collected with the structure of work packages and work content is defined by takt production. While new data and information is collected, the project simultaneously benefits from using old knowledge tied to the work packages. This system provides a standardized production process over time that can be systematically developed.

One centric element of the process model is the division of information and data types based on whether it can be tied directly to work packages or not. This system directs explicit knowledge directly into work packages. Simultaneously, tacit knowledge from projects is collected with a defined system that creates fewer barriers for personnel to participate; the current procedures are evaluated based on monitoring project records. This allows for updates to procedures based on knowledge justified by data, and the categorization simplifies the presentation, addressment, and implementation of new information in an organization (Rezgui, 2001; Dalkir, 2017). To handle information based on this categorization, two already known solutions in the company (updating the database and expert sharing knowledge) are used as main methods to implement new information, and to connect the new system to familiar methods of the organization (Barber et al., 2006; Moffett et al., 2004).

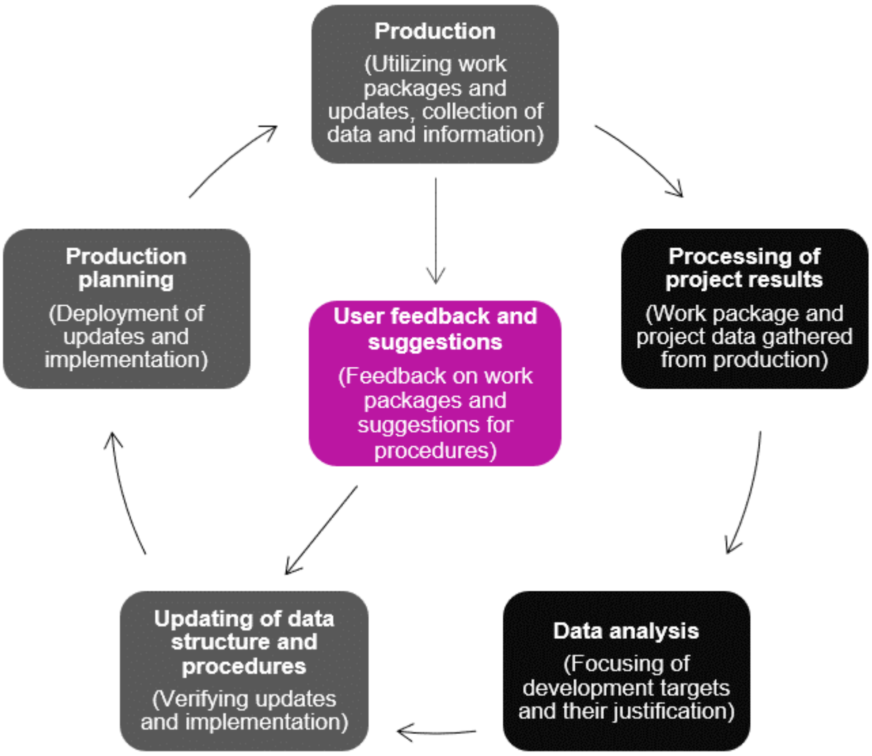

Figure 2: Process model of the continuous improvement of takt production presented in a project environment.

According to the categorization of information and data, there are four different types of processes that address information from the collection to the implementation stage. All four processes follow the three-step-structure proposed by Lehtovaara et al. (2019): collecting information and data, addressing information, and implementation. The content of these steps is formed to all processes (Table 1) by applying the idea of knowledge types (Nonaka and Takeuchi, 1995), filtering and analyzing of knowledge (Crossan et al., 1999), and categories of preserved information (Blackler, 1995). The processes shown in Table 1 are tied to the process model so that user feedback and suggestions follow the pink (middle) path, and analysis processes follow the black (circle) path, while both are connected to project execution with the grey steps (Figure 2).

After each project obtained feedback, and data are addressed to recognize potential development targets in the current production process. Additionally, data can be run through automated analysis to obtain analytics to support decision making if data is collected according to the defined methods with adequate quality. Having structured information and analyzed data will enable extensive root-cause analysis to support continuous improvement. The continuous improvement process can be roughly described in a hypothetic takt project as follows:

1. Production planning: creation of takt plan by using work packages of the organization, so that the familiar work packages can be applied in takt planning of a project constructing a relatively known product, simplifying the task of defining takt areas and work sequences.
2. Production: utilization of the familiar work packages that are continuously adjusted to fit the current project, while simultaneously enabling improvement.
3. Processing of results and data analysis: learning from information gained in a project to ensure that the creation of the next takt plan will account for the lessons learned in the previous project of constructing a relatively similar product.

Table 1: Content of the steps required to handle information to guide the categorized information processes.

Information process	Step 1: Collecting data and information (Worksite personnel)	Step 2: Addressing information (Development organization)	Step 3: Implementation (Development organization and worksite personnel)
Update based on user feedback	Current work package as initial data. Update based on simple modification to content of package.	Update is edited to content of work package with basic information of project and reason for update.	Person in charge for work package checks and agrees to modification, after which users can see the update. (Updated work package.)
Update based on analysis of data	Work package specific data collected as initial data, supported with memos and results of project.	Inspection of data to search improvement targets, with methods such as statistics and data mining.	Update of instructions of work package or editing current work packages. Information sharing ensured with info or trainings. (Updated work package.)
Update based on user's suggestion	Solution found in community of practice or suggested development by individual.	Adapting solution to current procedure and forming instructions to implementation.	Information sharing with info or handouts, supported with specialist implementation if necessary. (New or updated procedure of working.)
Update based on analysis of operations	Work package specific data collected as initial data, supported with memos and results of project. Root cause analysis is encouraged.	Assembled analysis of data and memos to justify and explain the need of update, formed into procedure. Root cause analysis is encouraged.	Project-specific implementation to ensure adequate support and correct interpretation of new or updated procedure. Supported with info and training. (New or updated procedure of working.)

VALIDATION AND DEVELOPMENT OF THE MODEL

REVIEW OF FEEDBACK

The external focus group responded to a questionnaire about the proposed requirements of the data and the development targets of the continuous improvement of takt production in construction. The responses to the requirements of data express that there is clearly a need to focus on the quality of data collection, since the requirements are currently not widely fulfilled. The respondents mostly agreed to present development targets that were used to form the process model, which can be interpreted so that the focus of the process model is suitable for practical needs.

The most upstanding development targets of external feedback were the lack of a standardized takt production process, and the fact that data collection and processing are not sufficiently guided to support development. During the discussion about the presented process model, the focus group brought up observations of two main challenges that may occur in the implementation: 1) the encouragement of personnel to provide feedback to the current production process, as updates following the feedback will often be visible only after the project is finished, and, 2) disunity of the used takt production terms could lead to misunderstandings if the terms vary inside the organization.

The feedback from the case company focused on the implementation of, and how to ensure success of the implementation of the process model. The most critical remark was that the steps of the process model must be comprehensible to ensure that site personnel understand the content as intended and that the actual development benefits are grasped on site. In total, it was found that the ongoing development system required clarification for site personnel, and that the process model seeks to solve this issue.

REMARKS FOR FUTURE IMPLEMENTATION

There was no evident need to make modifications to the structure or content of the process model according to the obtained feedback. However, there were a few remarks introduced that must be considered during the implementation and possible expansion to other functions, apart from the construction production process:

1. Agreeing on mutual takt production terminology across the organization (or industry). (External feedback.)
2. Defining persons in charge for work packages to monitor updates and viability. (Internal feedback.)
3. Creating a quick and easy-to-use feedback system and guiding the use of it. (External and internal feedback.)
4. Encouraging feedback and development ideas to create an ethos of improvement. (External and internal feedback.)
5. Defining a schedule for handling feedback and updating the content of the data structure (work packages). (Internal feedback.)
6. Harmonization of other operations (such as procurement) with the takt production structure and work packages. (External and internal feedback.)
7. Verifying that each update or modification to the production process is implemented with adequate support from specialists responsible for change. (Internal feedback.)

DISCUSSION

The goal of connecting takt production and knowledge management was approached in this study by creating a process model that utilizes the terminology and methods of takt production, while seeking to develop this system with guidelines from knowledge management. Although the process model was created to serve the needs of building a parking center, the same principles can be applied to improve production processes of other construction product types. Considering on earth construction, roughly the same guidelines for the creation of a takt plan can be applied and improved through information handling to enhance the knowledge tied to work packages and sequences. When subterranean construction is considered, there is a need to define the takt production guidelines for such projects that do not follow the same restrictions of constructability. However, when a takt production system is created for subterranean projects, there is no apparent reason why the same guidelines of continuous improvement would not apply.

Apart from the production process planning and control, other construction companies' functions are currently working with the project information as it is provided to them. Currently, cooperation between site and other functions is very project specific, which causes work to be defined by the form of information provided. If the project information is provided in a standard form defined by a takt plan, there is a possibility that other functions, such as procurement, could develop their operations around the work package information as well. Work packages would have definitions of work that include more information other than quantities and rough verbal estimates of work difficulty, which will lead to more precise estimations of work hours and costs in general.

While the idea of takt production enabling continuous improvement was presented by Dlouhy et al. (2016), there was no sufficient presentation of how data and information should be managed in practice (Bilal et al., 2016) to accomplish continuous improvement. This study presented one verified method on how this improvement could be achieved in practice. However, it requires long-term verification to ensure that the presented model is eligible due to the limited scope and material in this study alone.

Using the work packages and sequences of takt production to address explicit knowledge is presented in this study with depth and can be applied in practice to form a standardized production process for continuous improvement (Liker, 2003). However, the model's current presentation of tacit knowledge categorization is not as accurate as what is presented in the literature (Blackler, 1995; Nonaka and Takeuchi, 1995). The methods surrounding the handling of tacit knowledge proposed in the process model should be sufficient to start the improvement process in practice, but should be further studied to form a complete knowledge management strategy.

CONCLUSIONS

The management of information and data can be organized by following the methods presented in knowledge management literature. Management of information alongside the terminology and methods of takt production can be used to create a standard production process so that collected information and data can be directly tied to production processes. Describing a continuous improvement system with a process model helps spread knowledge to the personnel of an organization, which reduces the threshold to participate in learning. By utilizing familiar, well-functioning implementation methods, the model can be tied to current practices and, thus, the model is easier to adapt to various projects. Updates of work packages make improvement visible to project personnel, thereby encouraging people to submit more feedback for continuous improvement.

Further research is suggested to verify the presented process model's long-term success in practice. After proving functionality to the process model, it is possible to further research the model's adaptive ability in other construction functions. When construction operations are run with well-defined takt production processes, it is easier to improve cooperation with stakeholders, such as subcontractors, by utilizing information provided by the work packages.

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