Sahlberg, Jenni; Lehtovaara, Joonas; Seppänen, Olli

Implementing Takt Production in Renovation Projects

Published in:
29th Annual Conference of the International Group for Lean Construction

DOI:
10.24928/2021/0113

Published: 01/07/2021

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Sahlberg, J., Lehtovaara, J., & Seppänen, O. (2021). Implementing Takt Production in Renovation Projects. In *29th Annual Conference of the International Group for Lean Construction* (pp. 677-686). (Annual Conference of the International Group for Lean Construction). IGLC.net. https://doi.org/10.24928/2021/0113

Sahlberg, J., Lehtovaara, J., and Seppänen, O. (2021). "Implementing Takt Production in Renovation Projects." *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC29)*, Alarcon, L.F. and González, V.A. (eds.), Lima, Peru, pp. 677–686, doi.org/10.24928/2021/0113, online at iglc.net.

IMPLEMENTING TAKT PRODUCTION IN RENOVATION PROJECTS

Jenni Sahlberg[1], Joonas Lehtovaara[2], and Olli Seppänen[3]

ABSTRACT

Renovation projects are a special type of construction projects. The unique features of renovation projects make production control challenging, as they often cause a great deal of variation, resulting in waste in production and reducing profitability. Takt production has been applied to renovation, but its specific suitability and benefits in renovation projects have not been studied widely.

This paper describes a design science study that i) examines the suitability of takt production in renovation projects through literature and interviews, ii) designs a process model for applying takt production in renovation projects, and iii) applies and validates the designed process model in a case project.

The findings imply that takt production can benefit renovation projects. The study highlights the significance of fulfilled prerequisites and well-managed supporting functions in takt production. If these requirements are not fully met, the significance of proactive problem-solving in production control and collaborative practices increases.

KEYWORDS

Design science, lean construction, takt planning and control, renovation.

INTRODUCTION

Renovation projects – that commonly include complex and unpredictable production systems – often suffer from low productivity (Kemmer 2018). Solutions for these productivity problems have been sought from the production planning and control methods within the domain of lean construction. The fundamental aim of lean construction is to employ flow and maximize the value-creation for the customer (e.g., Bertelsen and Koskela 2004). These elements are critical in renovation projects in which poor production flow can lead to chaos, and the customer often has strict limitations for the production schedule and sequence of renovated areas (Kemmer 2018).

The main goal of takt production is to plan and control the production in a way that allows it to proceed in a steady rhythm, leading to increased production flow (resulting in, for example, reduced durations; e.g., Kujansuu et al. 2019) and maximized customer value (Binninger et al. 2017; Haghsheno et al. 2016). Takt production has been mostly studied and applied in interior phases of new buildings (e.g., Lehtovaara et al. 2019; Vatne and Drevland 2016), with some applications in renovation projects such as in interior

[1] Site Engineer, YIT Suomi Oy, Finland, jenni.sahlberg@yit.fi, orcid.org/0000-0001-8498-6230

[2] Doctoral Candidate, Department of Civil Engineering, Aalto University, Finland, joonas.lehtovaara@aalto.fi, orcid.org/0000-0002-4761-3811

[3] Associate Professor, Department of Civil Engineering, Aalto University, Finland, olli.seppanen@aalto.fi, orcid.org/0000-0002-2008-5924

phase and MEP assembly (e.g., Tommelein 2017; Binninger et al. 2018). However, implementation in other renovation work phases, such as demolition, and detailed investigation of specialties of renovation construction, remain scarce. Some argue that takt production can be challenging to implement in projects that hold a large amount of variability (e.g., Vatne & Drevland 2016), while other research presents takt production as an optimal method for reducing variability in these instances while enhancing flow and value-creation (e.g., Tommelein 2017). Nevertheless, takt production's suitability to complex and non-repetitive renovation has not yet been evaluated; therefore, further studies of takt production in this specific domain are needed.

This study's main objective is to evaluate whether takt production forms a suitable production planning and control method for renovation projects, and if yes, what restrictions, preconditions, and benefits might be associated with the method. In addition to evaluating the suitability, a process model of takt production in renovation projects is formed and tested. The study was set to focus on large renovation projects where the general contractor is also responsible for demolition and design management operations (i.e., Design-Build) and in which the future occupant or customer is also heavily involved in the design process, as usually in renovation projects (Aalto et al. 2017). The study is limited to the construction phase; thus, the handover phase is not included in the study.

RESEARCH DESIGN

The study was conducted as a design science research (DSR), which is an iterative research method aiming for developing a solution or a tool for an existing problem (Holmström et al. 2009). DSR starts with a challenge or an interesting opportunity to implement a known practice in a new context, forming a suitable approach for searching for solutions to practical problems like construction management issues (Rocha et al. 2012). Therefore, it is justified to use DSR to implement takt production in complex renovation projects. The study applies a five-step approach of DSR (adopted from Holmström et al. 2009), presented in Figure 1.

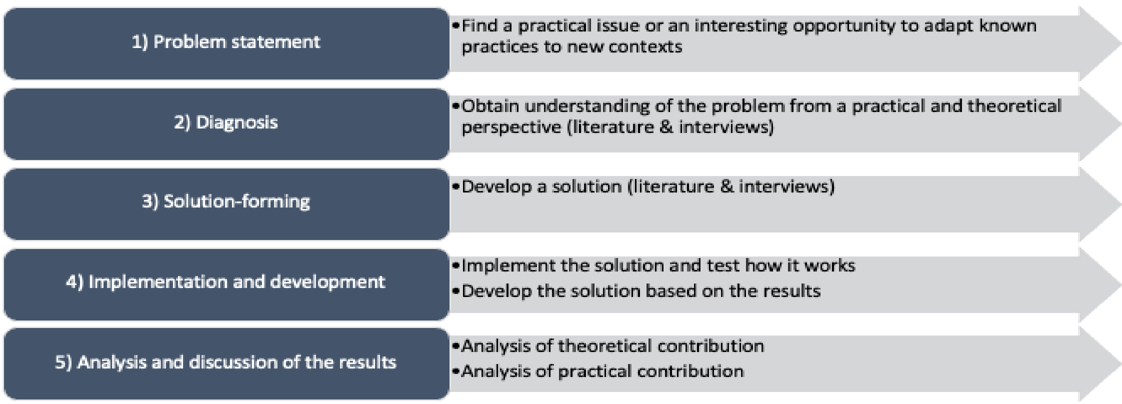

Figure 1: The structure of the research

First, a specific problem is defined, presented in the introduction section. Second, the diagnosis of the problem is conducted based on the literature review (consisting of the relevant takt production and renovation construction literature) and 12 semi-structured interviews, including nine site managers, supervisors and engineers, one representative from an MEP and a demolition company each, and one lean construction consultant. The diagnosis aimed to synthesize information about the prevalent takt production methods and practices in renovation projects, utilizing earlier experiences from case examples, and to gain complementary professional knowledge of the subject. Third, a solution – the process model for applying takt production into renovation projects – was developed. Fourth, the process model was tested through implementation in a complex renovation project. The solution's feasibility was examined through qualitative analysis, including the analysis of the progress of construction and mechanical, electrical, and plumbing (MEP) work tasks, seven semi-structured interviews among the case project organization, accompanied by production meeting, document, and site observations. The first author took an active role in implementing and testing the process model through the fourth phase, participating in planning and controlling the production during the implementation. Finally, the results were analyzed, and the contributions of the study were discussed.

DIAGNOSIS AND SOLUTION-FORMING

TAKT PRODUCTION IN CONSTRUCTION

Three different takt production methods and their previous implementation were considered in the diagnosis; these methods were selected due to the availability of descriptions in international, peer-reviewed journal and conference papers. These methods are Takt Planning and Takt Control (TPTC) (e.g., Binninger et al. 2017), Takt Time Planning (TTP) (e.g., Frandson et al. 2013), and process model for implementing takt production intro ship cabin refurbishment (Heinonen and Seppänen 2016).

While all the methods offer quite a similar approach and a systematic process to follow, certain differences can be found between the methods. TPTC is highly structured and top-down oriented (e.g., Dlouhy et al. 2018a) whereas the collaborative practices of TTP answer more to social needs and commitment process from down to up (e.g., Frandson et al. 2013). The ship cabin refurbishment method focuses on aggressive top-down implementation while aiming for radically small batch sizes. The latter method also offers a clear connection between production flow, value-creation, and management of supporting functions, such as logistics (Heinonen and Seppänen 2016).

Collaborative practices in production planning can increase the level of commitment and the reliability of work (Kujansuu et al. 2019). However, just involving everyone as early as possible does not necessarily ease the process, especially in complex takt production projects (Lehtovaara et al. 2019). Thus, the number of the participants in production planning and control and the timing of their participation should be considered carefully and based on project-specific characteristics (Frandson 2019).

Although clear repetition of processes and a small amount of variability greatly helps the planning and control process (e.g., Haghsheno et al. 2016; Vatne and Drevland 2016), takt production is not only limited to cases with a high amount of repetition and low variability (e.g., Tommelein 2017). Variability can be effectively managed by applying time, capacity, inventory, or plan buffers (Dlouhy et al. 2019), with a preference on capacity buffers that are often underutilized in current planning and control practices (Frandson 2019). By decreasing batch size, production can be paced more tightly, resulting in a decreased duration (Dlouhy et al. 2019). However, with more uncertain and complex projects, control of tightly-paced production can be challenging. For these kinds of projects, an increased amount of buffers are needed (Vatne and Drevland 2016), and reliability in starting data is essential to form a sound takt plan (Tommelein 2017).

As construction production often involves tasks that optimally would proceed in different rhythms or directions (Frandson 2019), TPTC offers phasing as a solution (Dlouhy et al. 2018b). Phasing allows a fluent synchronization of differently orientated phases, aiming for better overall optimization of production (Gardarsson et al. 2019) while maintaining reasonable resource flow and productivity, for example, in MEP installation (Dlouhy et al. 2018b). However, phasing benefits the project only if different phases are coordinated so that prerequisites of all work tasks will be fulfilled (Dlouhy et al. 2018b).

RENOVATION PROJECTS

Renovation projects differ from the construction of new buildings in two significant ways. First, there are special work tasks in renovation construction, including demolition of structures and hazardous materials, structural changes, preservation, and conservation tasks that do not exist in constructing new buildings (e.g., Kemmer 2018; Ma et al. 2015). These tasks require particular professional knowledge of work methods, materials, and safety to plan and execute (Ma et al. 2015).

Second, the unique characteristics of renovation projects should be considered in the planning and control process. According to Kemmer (2018), when entering into a renovation project, an organization should understand the building's current conditions, the full content of the necessary construction tasks, and both the existing and the future operations in the building. It is quite common that the condition of an existing asset is not fully communicated or researched (e.g., Mitropoulos and Howell 2002). As-built conditions are available only after demolition and structural changes phases, creating a vast amount of uncertainty (Aalto et al. 2017) and possibly leading to significant schedule deviations and design changes during the construction. Therefore, the content or the scope of renovation can aggressively change through the production. In addition, the planning and control of operations are strictly connected to value-creation, as the needs of the present or the future occupant and their operations often define the schedule and the sequence of renovation (Kemmer 2018).

INTERVIEWS

Current Practices

According to the interview results, takt production has been implemented so far in renovation projects in various ways. In total, five earlier takt production projects were discussed. In two of them, takt production was abandoned during the control phase due to the lack of earlier takt production experience or several design changes. However, there were also positive experiences, especially in three other projects. Even though these projects were executed with different takt methods, a common factor was that the general contractor was always in the lead and the subcontractors participated in detailed takt planning and takt control phases, in which collaborative practices (like the Last Planner System, LPS; Ballard and Tommelein 2021) or digital tools were utilized.

Prerequisites, Challenges, and Benefits

In addition to mapping the current practices, findings considering prerequisites, benefits, and challenges in applying takt production in renovation projects were gathered. The interviewees highlighted the importance of prerequisites for effective takt production, including the following main points: i) adequate design and other starting information, ii) early procurement so that the necessary preconditions of takt production are written in contracts and contractors can participate in production planning, iii) planning logistics and defining logistic practices in procurement contracts, iv) participation of the whole supply chain including subcontractors and material suppliers, v) commitment of the main contractor’s organization and quality of the daily production control routines with vi) implementation of practices and software that support takt planning and control. It should be noted that most of these prerequisites are valid for any takt projects and just the first one is impacted by special conditions of renovation projects.

According to the interviews, challenges of takt production are connected to the main prerequisites listed above, supporting the results of the literature review. The absence of preconditions leads to a challenging planning process and further unnecessary changes, making-do (Koskela 2004), and waste during the production. The interviewees argued that the benefits of takt production are most visible during the production control. Takt plan is an easily understandable and transparent tool that can generate time savings while increasing commitment and collaboration. Interviewees reported positive outcomes of shortening the overall duration in a hotel and office refurbishments and embraced the transparency of dependencies of work tasks generated by takt production implementation. In addition, preventing accumulated rush and cascading delays at the end of the production was considered to be important. Some of the interviewees argued that the benefits, e.g. time savings are more likely to be achieved in repetitive production.

PROCESS MODEL

Based on the diagnosis, a solution – formed as a process model – was developed. The process model was set to cover the following issues in renovation production planning and control: i) prerequisites, including starting data changes generated from demolition, ii) commitment through collaborative practices, iii) sufficient knowledge and skills through an organization and iv) integration of the support functions of production, e.g., procurement, logistics, and design management. The process model is called *three-phase takt production in renovation projects*. More detailed description of the process model can be found in (*omitted for peer review*)

The process model allows to divide production into particular phases planned and executed individually, including a possibility to apply different takt planning parameters (such as takt time) to different phases (Dlouhy et al. 2018b). The phases of a renovation project are i) preparation, that aims for ensuring the preconditions for the interior phase, ii) interior and iii) finish (Figure 2). Earlier takt production documentation from renovation projects implied that MEP assembly should be integrated with other interior phase tasks (e.g., Tommelein 2017; Frandson 2019). The rest of the tasks are gathered from the interviews and Finnish construction guideline database (Rakennustieto Oy 2011). Notably, there should be a time buffer in between phases e.g. for design update needs occurred during demolition.

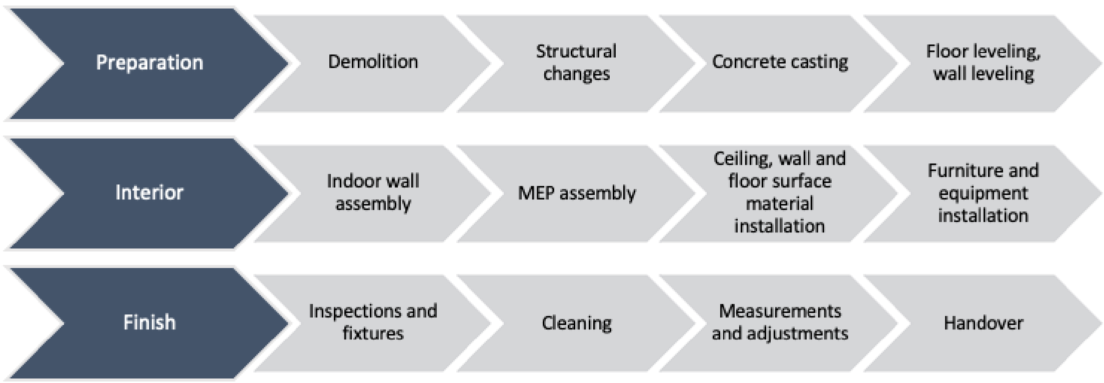

Figure 2: Three-phase takt production in renovation projects

The process model is structured according to the three-level (macro-norm-micro) approach of TPTC (Dlouhy et al. 2018a). The macro level covers process definition and customer priorities (Dlouhy et al. 2018a). In the process model, the macro level includes the three-phase takt production presented in Figure 2, aiming for standardization of the production timeline of renovation projects. In TPTC, the norm level consists of detailed takt and support function planning process and the micro level represents takt production control and coordination on work task level (Dlouhy et al. 2018a). The process model includes step by step instructions for these levels, see (*omitted for peer review*).

The process model is also applicable for projects with inadequate takt production prerequisites, e.g., starting data, because preliminary planning can start before all the procurements are done and some information is still lacking. General contractor is responsible for the whole process and other production participants are included from detailed takt planning phase, adapting collaborative practices on the level that the project size and complexity requires and allows. Increasing the level of commitment (e.g., Kujansuu et al. 2019; Gardarsson et al. 2019), and communication especially in complicated projects (Kemmer 2018) are embraced by implementing collaborative practices (e.g. TTP process, Frandson et al. 2013 or LPS, Ballard and Tommelein 2021).

IMPLEMENTATION AND DEVELOPMENT

CASE DESCRIPTION

The process model was tested by implementing it into a renovation project that included significant risks, i. e. unaccomplished designs, unexposed structures where the major changes were due, a short production planning time, and a customer-defined overall duration. According to Aalto et al. (2017), this is a typical setting in a renovation project, therefore suitable and interesting starting point for the implementation. The case project is an office building from 1994, not including any hazardous materials. The renovation consisted of the full modernization of the office spaces including MEP systems and construction of new stair connections. Also, the façade and the roof were refurbished.

IMPLEMENTATION OF THE PROCESS MODEL AND DATA ANALYSIS

The testing of the process model was executed in two very similar office floors that were punctured by the new stair shafts and a few local changes on façade structure. The floors were divided into four almost identical ~780 sqm takt areas based on the repetitive work and the MEP service areas, and the takt time was set as five days based on the work quantities and required lead time. In addition, the case project was the first takt production project for every participant in the project, and the clear rhythm in a week was considered beneficial. The study included one iteration round of the process model. The three-phased process model and its production planning steps were followed according to the process model from demolition to interior phase. The MEP contractor participated in detailed planning through several comment rounds and LPS meetings which were a chosen collaborative production planning tool in the case project. The implementation was found to be mostly successful. The participants supported the three-level takt production (Figure 2) and argued that it made the occurred deviations of production visible and buffering useful. Some difficulties in following the process model appeared in the control phase, mostly because of the global Covid-19 pandemic restrictions and the organization's lack of previous takt production experience.

The demolition phase was executed according to the plan otherwise, but after exposing the structures, the new stair shafts were found to be different than assumed. Thus, the main delays in the construction tasks were the last 5 percent of the work located around the stair shafts, and it was executed by another work group that focused only on the delayed worktasks. There was also need for a few production control adjustments and a couple of wagons were delayed because of a temporary lack of calculated resources, especially when the second floor started. These adjustments were handled through daily takt control routines and were not updated to the takt plan. In addition, to improve flexibility, three buffer wagons were transferred from the end into the trains during the production. The final version of the takt plan containing the buffer wagons is in Figure 3.

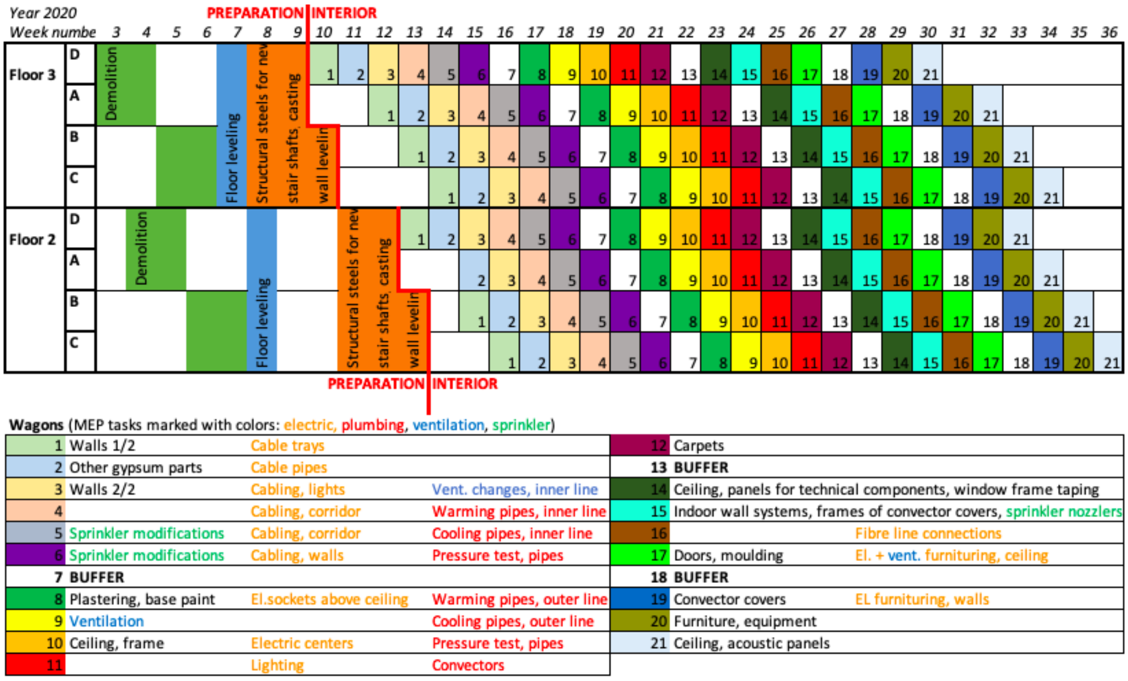

Figure 3: The final takt plan of the case project (preparation and interior phases)

The progress analysis showed that MEP installations started as planned, but electricity assembly started to fall behind soon after cabling tasks were started. The main reason for the delay was the customer's lack of unambiguous information about the requirements of electricity assembly. Thus, design changes occurred during the installation. Plumbing proceeded quite well except for the overlapping production trains that required doubled resources. Ventilation installations were the most challenging task to schedule and execute because the work was done inside the existing fireproofed steel structure intermediate floor. In short, the execution started before and ended after planned dates. The occurred challenges and other delays than the stair shaft related occurred after five weeks of takt production, indicating production control issues.

In addition, the MEP contractor expected more flexibility when the main contractor assumed a full and exact commitment to the takt plan. The takt control meetings were held between the main and the MEP contractor because the other subcontractors followed the schedule quite intuitively. However, the MEP contractor found the level of communication partly inadequate, and the stakeholders had some disagreements that can be a partial cause for issues in production control. Also, collaborative practices in production control were found to be challenging without digital tools, and COVID-19 pandemic put additional challenges on conducting collaboration effectively.

REFLECTION AND DEVELOPMENT OF THE PROCESS MODEL

According to the interviews made amongst the case site organization, the implemented three-phase model was almost unanimously supported, offering a solid base for further development. The interviewees agreed that the timing and the level of their participation in production planning was suitable to the project. In addition, the lead time of the takted areas was reduced by 30 percent compared to the traditional scheduling approach. Major changes to the process model were not suggested due to the promising results. However, specifications to clarify daily production control policies were made so that the process model would be more suitable for the organizations lacking previous takt production experience. Also, the role of participation of an MEP contractor and other partners were suggested to be specified more clearly based on the project specified requirements.

DISCUSSION OF THE RESULTS

Our case study results demonstrate that takt production can be successfully implemented in renovation projects, and even relatively easily if the system possesses clear repetition of processes and a small amount of variability. In the case project, the implementation was set not to cover the whole production but was limited to repetitive areas. The validation of the process model should be continued in different types of renovation projects containing different levels and appearances of repetition and uncertainty.

The study showed the significance of fulfilled prerequisites in takt production. Even though it was found in the case project that takt planning and even takt control can be started with imperfect prerequisite conditions, with better starting data, it would have been possible to create more accurate and reliable plans. If there are significant deficiencies or delays in the prerequisites, an organization should prepare itself to schedule changes and proactive problem-solving during production control. In this case, short-cycled and systematic control of takt production control is extremely essential. If delays occur, an additional crew can execute delayed work tasks following the main train. If these matters are taken care of, the study implies that the predictability and controllability of renovation projects can be improved with takt production.

The case project also showed that the early recognition of bottleneck tasks or a lack of critical input data improves the preconditions for successful takt production. The phasing of the production into three phases according to the process model was found to be a suitable approach. However, all potential distractions and deviations that affect the interior phase should be examined in the preparation phase. In the case project, recognizing the stair shafts as a significant bottleneck earlier would have been a great benefit. Also, a thorough review of the full content and preconditions of MEP work packages, e.g., cabling, should have been done more carefully. Based on the diagnosis and the data analysis, a separate development phase between demolition and construction phases could be considered to allow the implementation of takt production into more uncertain and high-variability areas. In addition, the possibility of classifying design update needs based on their urgency should be considered to minimize the delay. Also, late customer decisions generated significant difficulties to takt production, thus, the management of the customer relationship is a key factor in a successful implementation.

The results demonstrate two different commitment modes of subcontractors. In the case project, the MEP contractor involved in the scheduling through the process model but was not fully committed to the schedule, while other subcontractors worked according to takt schedule even if they did not participate in the planning. This shows that even collaborative practices do not guarantee commitment. Thus, the readiness for implementing takt production should be weighed in the procurement process. A digital software could increase the transparency and trust between stakeholders, being the most significant development suggestion by the MEP contractor.

Finally, when implementing takt production, the previous experience of the key people must be taken in account, as it certainly influences the commitment level towards the method. Based on the case project, it seems important to change practices little at a time and allow the slow development of culture and skills. The role of training and education should be considered, and the complexity of a takt plan can be increased only by teaching and gathering experience about takt production. This was aligned with the claim that the benefits are more likely to be achieved first in repetitive renovation projects.

The limitation of the research was that no data was collected related to flow of resources and materials. In future research, additional data should be collected to analyze if renovation projects impact resource flows in takt production.

CONCLUSIONS

This study was conducted to examine the usability of takt production in renovation projects. The results show that takt production can be a suitable method for renovation projects, even if the prerequisites are not fully accomplished, if production control supporting functions are handled proactively and collaboratively. By including a development phase between demolition and construction phases, takt production could offer a suitable method in planning and controlling projects with more uncertainty and high variability. In addition, phasing of the production was seen as effective in managing deviations that are common in renovation projects. Takt production practices should be implemented incrementally and considering the previous takt production experience of organization to increase the ability to apply takt production also in complex renovation projects containing a high amount of variability.

Future research should study the possibilities of takt production in different kind of renovation projects, including housing, hotel and industrial premises, focusing also on less repetitive production that includes more uncertainty and renovation specific work phases, e.g., abatement and demolition of other hazardous materials and conservation. This can be done according to the process model instructions and approaches presented in previously documented takt methods. In addition, the applicability of different options to increase flexibility should be studied. Further research should also strive for a deeper understanding of the coordination between MEP and construction tasks.

REFERENCES

Aalto, T., Saari, A., Junnonen, J-M. (2017). *Vaativien korjaushankkeiden ongelmat ja niiden torjunta: Vaativien korjaushankkeiden johtaminen -tutkimuksen osaraportti 1.* Tampereen teknillinen yliopisto. Rakennustuotanto ja -talous. Raportti; vuosikerta 22.

Ballard, G., Tommelein, I.D. (2021). *2020 Current Process Benchmark for the Last Planner® System of Project Planning and Control*. University of California, Berkeley.

Bertelsen, S., Koskela, L. (2004). Construction Beyond Lean: A New Understanding of Construction Management. Proceedings (IGLC12). Helsingør, Denmark.

Binninger, M., Dlouhy, J., Haghsheno, S. (2017). Technical Takt Planning and Takt Control in Construction. Proceedings (IGLC25). Heraklion, Greece.

Binninger M., Dlouhy J., Müller, M., Schattmann, M., Haghsheno, S. (2018). Short Takt Time in Construction – A Practical Study. Proceedings (IGLC26). Chennai, India.

Dlouhy, J., Binninger, M. Haghsheno, S. (2019). Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems. Proceedings (IGLC27). Dublin, Ireland.

Dlouhy J., Binninger M., Oprach S., Haghsheno S. (2018a). Mastering complexity in Takt planning and Takt control - Using the three level model to increase efficiency and performance in construction projects. Proceedings (IGLC26). Chennai, India.

Dlouhy J., Oprach S., Binninger M., Haghsheno S. (2018b). Using Taktplanning and Taktcontrol in Production Projects – Comparison of Construction and Equipment Phases. Proceedings (IGLC26). Chennai, India.

Frandson, A. (2019). *Takt time planning as a work structuring method to improve construction work flow*. Doctoral dissertation. UC Berkeley.

Frandson, A., Berghede, K., Tommelein, I. D. (2013). Takt time planning for construction of exterior cladding. Proceedings (IGLC21). Fortaleza, Brazil.

Gardarsson, M. H., Lædre, O., Svalestuen, F. (2019). Takt Time Planning in Porsche Consulting, The Boldt Company and Veidekke. Proc. (IGLC27). Dublin, Ireland.

Haghsheno, S., Binninger, M., Dlouhy, J., Sterlike, S. (2016). History and Theoretical Foundations of Takt Planning and Takt Control. Proc. (IGLC24). Boston, USA.

Heinonen, A., Seppänen, O. (2016). Takt Time Planning in Cruise Ship Cabin Refurbishment: Lessons for Lean Construction. Proceedings (IGLC24). Boston, USA.

Holmström, J., Ketokivi, M., Hameri, A. P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences*, *40*(1), pp. 65-87.

Kemmer, S. (2018). *Development of a Method for Construction Management in Refurbishment Projects.* Doctoral dissertation, University of Huddersfield.

Koskela, L. (2004). Making-Do – The Eighth Category of Waste. Proceedings (IGLC12). Helsingør, Denmark.

Kujansuu, P., Lehtovaara, J., Grönvall, M., Seppänen, O., Peltokorpi, A. (2019). Comparison of Collaboration and Trade Partner Commitment in Takt Implementation. Proceedings (IGLC27). Dublin, Ireland.

Lehtovaara, J., Mustonen, I., Peuronen, P., Seppänen, O., Peltokorpi, A. (2019). Implementing takt planning and takt control into residential construction. Proceedings (IGLC27). Dublin, Ireland.

Linnik, M., Berghede, K., Ballard, G. (2013). An Experiment in Takt Time Planning Applied to Non-Repetitive Work. Proceedings (IGLC21). Fortaleza, Brazil.

Ma, Y.-P., Hsu, C. C., Lin, M.-C., Tsai, Z.-W., Chen, J.-Y. (2015). Parametric Workflow (BIM) for the Repair Construction of Traditional Historic Architecture in Taiwan. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-5/W. 25th Int. CIPA Symposium, Taipei, Taiwan.

Mitropoulos, P., Howell, G. A. (2002). Renovation Projects: Design Process Problems and Improvement Mechanisms. *Journal of Management in Engineering*, pp. 179-185.

Rakennustieto Oy. (2011). Ratu 86-0388. Korjausrakentamisen erikoistyöt. Työlajit.

Rocha, C. G. Da, Formoso, C., Tzortzopoulos, P., Koskela, L., Tezel, A. (2012). Design Science Research in Lean Construction: Process and Outcomes. Proceedings (IGLC20). San Diego, California, USA.

Tommelein, I. D. (2017). Collaborative Takt Time Planning of Non-Repetitive Work. Proceedings (IGLC25). Heraklion, Greece.

Vatne, M. E., Drevland, F. (2016). Practical Benefits of Using Takt Time Planning: A Case Study. Proceedings (IGLC24). Boston, USA.