Takt production and decentralized decision-making: improving construction production flow with novel planning & control approaches

Joonas Lehtovaara
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Abstract

The construction industry has come under growing pressure to build increasingly complex projects and to do so more efficiently. This dissertation explored how novel approaches—takt production and decentralized decision-making—could improve production planning & control practices while increasing production flow.

The dissertation employed a qualitative case study approach of three case studies, including a total of nine cases for which data were collected through 57 semi-structured interviews, observation of production and production documentation, and facilitation of takt planning sessions. Additionally, survey-based social network analysis (SNA, 53 responses) and a design science research (DSR) approach with expert workshops were used to support the case study strategy. By answering the research question—"How takt production and decentralized decision-making contribute to construction production planning & control practices and production flow?"—this dissertation’s primary contribution is threefold.

The first contribution is providing an understanding of the effects that different takt production domains and distinct drivers have on production flow and how they support takt production implementation, which allow for the systematic reaping of the possible benefits. Takt production seems to especially promote good process flow, and the benefits increase with increased implementation maturity. The second contribution is providing an understanding of how a better balance of centralized and decentralized decision-making could support an improvement of construction PP&C practices, deliberately considering both managers’ and production crews’ (consisting of crew leaders and first-line workers) viewpoints. The results suggest that employing decentralization can yield benefits for project performance, along with worker performance and well-being. In addition to examining takt production and decentralized decision-making individually, the third contribution is providing an understanding of their combined effect through formulating, implementing, and validating a decentralized takt production framework. Decentralized decision-making—when involving the first-line workers in the process—has the potential to improve the planning & control practices and complement the shortcomings of takt production, for example, by having positive effects on operations flow, even with the first implementation efforts.

Future research could consider investigating a larger range of diverse cases in an effort to examine improvement effects longitudinally; further explore the approaches through quantitative research methods to assess their impact more precisely; and further address the effects of a larger spectrum of flows, for example, project portfolio flow.

Keywords construction operations management, production flow, production planning and control, takt production, decentralized decision-making

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My interest in pursuing a doctorate began to emerge during my bachelor’s studies around 2015 and 2016. Alongside my studies, I was lucky to work as a trainee in organizations where applying research to practice was a highly appreciated craft, and understanding scientific thinking was considered an asset for a professional working in the construction industry. Since then, I started developing an idea of working on the boundaries of academia and practice. I increasingly caught myself thinking about how high-quality research could concretely improve industry practices, and simultaneously, how construction projects and organizations could fuel research. In 2018, in the finishing stages of my master’s studies, I made the commitment to pursue a doctoral degree. Even though committing oneself to one single project for roughly four years felt like a leap to the unknown, I intuitively felt drawn toward examining the construction practices through the lenses of science and communicating my findings through writing. I also felt excited about the opportunity to see closely how the state-of-the-art construction operations management research could mold the industry, which had shown weak signals of an upcoming change during my studies.

After several (or more likely, dozens) of research proposal iterations, my thesis was aligned towards examining novel construction production management practices, and more specifically, exploring how takt production and decentralized decision-making would affect planning & control practices and flow. At the time, takt production was a highly timely research avenue with a vast amount of scholarly and practical interest, while decentralized decision-making was an emerging practice that could produce interesting applications in the upcoming years. These two streams could also be combined (which we indeed did) and their joint effects examined. In hindsight, such a combination provided a fascinating playing ground for my four-year dissertation journey, full of learning opportunities and insights for short and long-term change. Through these four years, the focus of the dissertation remained relatively stable, simultaneously having a degree of flexibility when new and exciting avenues arose.

Reflecting back, this four-year journey was roughly divided into three periods. The first year-and-a-half was an immersive time of learning about my research topic, conducting sound scientific research, and communicating the results through writing, seminar presentations, and collaboration with industry partners. During the second and third year, the whole world had to reimagine the
ways of working through a pandemic that forced researchers to seek ways to collect data and collaborate remotely. For me, this was especially a period of deep focus in which I was lucky to have time to analyze, articulate, and review the results of the case studies I had already conducted. There is always a silver lining, even in the darkest cloud. For the fourth year I departed from Finland to Berkeley, California US, where I had an opportunity to collaborate with UC Berkeley’s Project Production Systems Laboratory, providing me a unique chance to look at all that I had learned from a new perspective.

I have to humbly admit I am extremely proud of my dissertation, its publications, and the whole journey over the last four years. It has been a pleasure to see how takt production and decentralized decision-making have matured in the past years in the Finnish construction research and industry context. Especially takt production has transformed from a potential, unforeseen method into a widely-acknowledged and systematic way of planning & controlling production – which a large proportion of Finnish construction professionals have at least heard of. I feel proud of being a part in this advancement through my research, and being part of the community that advances the construction industry in Finland and worldwide.

However, one should bear in mind that writing a dissertation is not an individual effort – far from it. Without all the support I have received during the last years, producing this dissertation would not have been possible. First and foremost, I owe thanks to Professors Olli Seppänen and Antti Peltokorpi for supervising and advising my doctoral studies. Their contribution in conducting and publishing research together, mentoring, and helping me grow as a professional has been extraordinarily helpful. Kasperi Koivu (and all the others from Fira), Pekka Kujansuu, Max Grönvall, Aleksi Heinonen, Risto Kärkkänen, Eelon Lappalainen, Rita Lavikka, Ergo Pikas, Jesse Miettinen, and all my colleagues from the Aalto Operations Management research group – thank you for your valuable time, your support, and all the discussions that have provided inspiring thoughts, resulting in us being able to conduct excellent research and advance the construction industry together. There are also dozens of others who I would like to acknowledge here but do not have enough space for – thank you all for your professional support.

Thank you Professor Iris Tommelein for hosting my research visit to University of California Berkeley, and thank you Vishesh Singh and Rafael Coelho (and all the others from the UC Berkeley EPM graduate program) for all the insightful discussions we had in McLaughlin room 407 (and in Triple Rock) – you made me feel extremely welcomed during my stay. I am also profoundly grateful for all the financial and technical support I have received for my research – thank you Aalto School of Engineering, Building2030 research consortium, DiCtion research consortium, Toimivat Katuhankkeet research project, Fulbright Finland, Technology Industries of Finland Centennial Foundation, KAUTE Foundation (The Finnish Science Foundation for Economics and Technology), Walter Ahlström Foundation, Ernst Wirtzen Foundation Fund, and Kiinteistöalan Koulutussäätiö.
Last but naturally not least, I want to express my gratitude for all the support I have received from my close friends and family. You are the reason I am the person today; without you, I would have not be able to produce this dissertation. Most importantly, thank you Siiri for all the support and genuine interest towards my work – in the past years, you have had an unimaginably important role in supporting me in achieving my goals and developing myself as a human being. As a concluding thought, I am truly grateful for the last four years and all the learnings and support I have received. I hope that, in some form or another, scientific thinking and writing will be part of me for the rest of my life.

Espoo, 14th of February, 2023
Joonas Lehtovaara
# Contents

Abstract.............................................................................................................................................

Tiivistelmä........................................................................................................................................

Preface and acknowledgements ...........................................................................

Contents...........................................................................................................................................

List of abbreviations ...........................................................................................................

List of publications.............................................................................................................

Author’s contribution ........................................................................................................

1. Introduction .............................................................................................................................. 1

2. Theoretical background .......................................................................................................... 7

3. Research philosophy and methods ....................................................................................... 21

4. Summary of the findings ........................................................................................................ 31

5. Discussion ............................................................................................................................... 47

6. References ............................................................................................................................... 59

Appendix: Publication 1 ..............................................................................................................

Appendix: Publication 2 ...............................................................................................................  

Appendix: Publication 3 ...............................................................................................................
**List of abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPM</td>
<td>Critical Path Method</td>
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<tr>
<td>DSR</td>
<td>Design Science Research</td>
</tr>
<tr>
<td>GC</td>
<td>General Contractor</td>
</tr>
<tr>
<td>IPD</td>
<td>Integrated Project Delivery</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-in-Time</td>
</tr>
<tr>
<td>LAP</td>
<td>Language/Action Perspective</td>
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<tr>
<td>LBMS</td>
<td>Location Based Management System</td>
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<tr>
<td>LBS</td>
<td>Location Breakdown Structure</td>
</tr>
<tr>
<td>LOB</td>
<td>Line of Balance</td>
</tr>
<tr>
<td>LPS</td>
<td>Last Planner® System</td>
</tr>
<tr>
<td>MEP</td>
<td>Mechanical, Electrical, and Plumbing</td>
</tr>
<tr>
<td>PP&amp;C</td>
<td>Production Planning and Control</td>
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<tr>
<td>SNA</td>
<td>Social Network Analysis</td>
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<tr>
<td>TPTC</td>
<td>Takt Planning and Takt Control</td>
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<tr>
<td>TTP, TP</td>
<td>Takt Time Planning, Takt Planning</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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<td>WIP</td>
<td>Work in Progress</td>
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List of publications

This doctoral dissertation consists of a summary and of the following publications, referred to in the text by their numerals.


Author’s contribution

**Publication 1.** How takt production contributes to construction production flow: a theoretical model

The publication is a qualitative multiple-case study that produced a theoretical model on how takt production contributes to construction production flow. The author conducted the study design with Seppänen, collected two-thirds of the data assisted by Kujansuu and Grönvall, carried out the data analysis, conducted the scientific writing, and led revising and editing. All the authors participated in revising and editing the paper.

**Publication 2.** Improving construction management with decentralised production planning & control: exploring the production crew and manager perspectives through a multi-method approach

The publication is a multi-method comparative case study of two cases that explored the effects of decentralization on construction production planning & control from the combined perspectives of production crews and managers. The author conducted the study design with Seppänen, led the data collection and collected one-third of the data assisted by research assistants Könkkölä, Haapasalmi, Joona, and Poukka, carried out the data analysis, conducted the scientific writing, and led revising and editing. All the authors participated in revising and editing the paper.

**Publication 3.** Combining decentralized decision-making and takt production in construction planning and control to increase production flow

The publication is an exploratory single-case study that, utilizing design science research, evaluated the effect of decentralized decision-making and takt production on production flow through formulating, implementing, and validating a decentralized takt production framework. The author conducted the study design assisted by Seppänen, collected all the data jointly with Lappalainen, carried out the data analysis jointly with Lappalainen, conducted the scientific writing, and led revising and editing. All the authors participated in revising and editing the paper.

The language of all three publications and the dissertation has been proofread and edited by Scribendi Editing and Proofreading. The author has personally examined the results of the language check, and it has not affected the scientific content of the dissertation.
1. Introduction

This study explores how takt production and decentralized decision-making contribute to construction production planning & control (henceforth PP&C) practices and production flow. The aim is pursued through three individual publications, and their combined contributions are synthesized in the present dissertation. This chapter presents the study context and highlights gaps in the current research, followed by the research questions, overarching research design, and study structure.

1.1 Study context and research gaps

1.1.1 Background

Construction is a project-based industry in which the projects form unique, complex entities with fragmented structures and numerous interdependent stakeholders (Baccarini 1996, Koskela and Vrijhoef 2000). While the complexity of projects constantly increases, there is a growing need to complete projects faster and with fewer resources (Dave et al. 2008). However, the construction industry has struggled to respond to these needs and increase its productivity, resulting in projects regularly suffering from cost and time overruns (Barbosa et al. 2017).

A key aspect in the success of construction projects—and the ability to respond to the above-mentioned needs—is effective PP&C (Koskela 1992). PP&C is a fundamental part of project production management, considering what needs to be produced, when and how (by utilizing adequate timing and methods), and how to coordinate and utilize the available resources to best meet the customer’s needs (Laufer and Tucker 1987, Vollmann 1997). The planning component provides a structure and direction for production. The control component considers how the production is executed accordingly and kept on track when unforeseen events occur and how the plan should be updated when opportunities for a better direction emerge (Arbulo et al. 2016).

One of the key aims of PP&C is to achieve high-quality production flow (Schmenner and Swink 1998), which reflects the productivity of production and is an essential element of all production processes. Flow represents the journey of transforming raw materials into products as they move through the value stream in which value-adding (and non-value-adding) activities are performed (Rother et al. 2003). High-quality flow occurs when the transformation journey
happens swiftly and evenly (Schmenner and Swink 1998) with a minimal amount of non-value-adding activities and variation (Shingo and Dillon 1989, Womack and Jones 2003).

During the past three decades, lean construction research in particular has invested considerable effort into developing new PP&C approaches to achieve more flow-efficient production. Especially the introduction of socio-technical PP&C approaches, such as the Last Planner® System (LPS; Ballard 2000) and the attempts to shift to use location- instead of activity-based PP&C approaches (e.g., Location Based Management System (LBMS); Kenley and Seppänen 2010) have shown their potential in improving flow by considering the utilization of locations as a key resource.

1.1.2 Takt production

Within the past 10 years or so, a novel location-based PP&C approach—takt production—has been receiving increased interest among scholars and practitioners because of its deliberate aim to holistically achieving high-quality production flow (e.g., Linnik et al. 2013). In addition to previous location-based approaches that focus on creating flow for production crews, takt production especially focuses on a stable cadence of processing products and client value creation.

Originating from operations management research, the term “takt” refers to the unit of time in which production activities must be completed in order to match the demand rate (Hopp and Spearman 2011). In construction, takt production aims to (1) plan the tasks to be completed in a unified rhythm that allows production crews to synchronously move from one location to another while matching the customer demand rate; (2) control the production to maintain the planned rhythm; and (3) continuously improve the production by tackling emerging problems and actively seizing learning opportunities (e.g., Dlouhy et al. 2016, Frandson et al. 2013).

The first references to takt production in project-based production have been connected to the sixteenth-century shipyards in Venice (Haghsheno et al. 2016) and the construction of the Empire State Building (where takt was referred to as “pacemaker”; Sacks and Partouche 2010, Willis and Friedman 1998). However, only in the early 2010s did takt production begin to appear more widely in construction management research studies (e.g., Frandson et al. 2013, Linnik et al. 2013). Since then, takt production has been introduced and studied under different names, the most well documented being takt time planning (TTP or TP, which has been primarily studied in commercial and hospital construction on the west coast of the US; e.g., Frandson et al. 2013) and takt planning and takt control (TPTC, which has been primarily studied in car manufacturing plant construction in Germany and Mexico; e.g., Dlouhy et al. 2016).

It is easy to see why takt production has garnered such a large amount of interest. Recent studies have shown that the approach has vast potential to improve construction PP&C practices and flow in various project types and sizes. The reported benefits from implementing takt production include reduced production durations (e.g., Binninger et al. 2018, Frandson et al. 2013), increased
production stability and predictability, lower costs (Linnik et al. 2013), fewer quality defects, increased trade productivity and increased safety (Heinonen and Seppänen 2016), reduced work in progress (WIP, work that has been started but has not yet been completed; Linnik et al. 2013), and increased transparency of communication and opportunity for collaboration and problem-solving (Frandson et al. 2014).

Despite the increased interest and potential benefits, takt production has been studied from relatively narrow viewpoints, primarily through individual, single (successful) case studies or method descriptions. To fully seize the potential of takt production in improving flow, there is a need to produce a more holistic understanding of the approach, critically analyze it, and build a bridge between the perceived effects and theoretical foundations of the operations management research. These efforts can help better understand takt production conceptually and practically, predict implementation outcomes more accurately, and generalize the requirements for successful implementation. These research opportunities and needs regarding takt production present the first gap addressed in the present dissertation.

1.1.3 Decentralized decision-making

In addition to providing structure and steering the direction of production to achieve high-quality flow, good (takt production) PP&C should have an inherently stable, predictable, and effective process while allowing for a comfortable working environment for the project stakeholders. Another strand of PP&C development that could answer these needs is decentralized and autonomous decision-making (e.g., Ben-Alon et al. 2014). In contrast to popular, hierarchical decision-making in which managers carry out decisions and command workers, in decentralized decision-making the management responsibilities are (partially) dispersed to the lower hierarchy levels (Mintzberg 1983). In the PP&C construction context, shifting to more decentralized decision-making structures could mean, for example, allowing production crews (consisting of crew leaders and first-line workers) to plan and control their work more autonomously.

The most widely used PP&C methods in construction, such as the Critical Path Method (CPM; Plotnick and O’Brien 2009), have been formed on the assumption that production can be effectively managed through fully central and hierarchical decision-making with managers or “master planners” organizing the production. However, in the context complex project-based systems (such as construction in which the degree of complexity and uncertainty constantly grows), this assumption has been disputed (e.g., Johnston and Brennan 1996) while the demand for more effective decision-making methods increases.

Although centralized decision-making possesses certain benefits (e.g., overall risk management; Lanaj et al. 2013), adopting decentralized practices to some degree could yield vast benefits (Bertelsen and Koskela 2005). These benefits, including increased planning & control predictability and efficiency, along with increased well-being and the creativity of workers, have been widely demonstrated in other fields, for example, automotive manufacturing (Liker 2005), the
military (McChrystal et al. 2015), and healthcare operations (Laloux 2014). In construction, the decentralization of PP&C (e.g., implemented through LPS) has demonstrated similar benefits, such as increased production performance (Castillo et al. 2018). Decentralized decision-making can also support takt production, which benefits from the production crews’ knowledge in planning, controlling, and improving the production system (e.g., Frandson et al. 2014).

However, even though it has been noted that construction PP&C could benefit from dismantling centralized decision-making, the first-line workers’ viewpoint on applying decentralized decision-making has been mostly missing in the literature. Moreover, construction management research efforts have in overall focused on managerial and crew leader viewpoints, even though exploring workers’ perceptions has been repeatedly suggested as a potential avenue of research (e.g., Diekmann et al. 2004, Hinze and Tracey 1994, Loosemore 2014). Because first-line workers form a vital part of the construction supply chain and a significant part of the industry workforce, it is alarming how little their viewpoints have been considered, which calls for increased attention in construction management research and the PP&C context. From these premises, there is a need to explore the improvement possibilities that decentralized (in contrast to centralized) decision-making could offer for construction PP&C practices, hereby taking into account production crews’ viewpoints, especially first-line workers.

Moreover, further exploring how takt production could benefit from decentralization provides an interesting possibility to improve both production flow and PP&C practices. Documented takt production cases (e.g., Vatne and Drevland 2016) have noted that workers’ missing involvement and lack of input in decision-making has led to implementation challenges, hindering the quality of flow. Combining decentralized decision-making involving first-line workers with takt production has not been previously studied. **These research opportunities and needs regarding decentralized decision-making, along with its combination with takt production, present the second gap addressed in the present dissertation.**

### 1.2  Research questions, overarching research design, and study structure

Considering the aforementioned research gaps regarding takt production, decentralized decision-making, and their combination, this dissertation explores how these novel approaches contribute to construction PP&C practices and production flow. From these premises, the main research question (RQ) is formed, standing as follows: **“How takt production and decentralized decision-making contribute to construction production planning & control practices and production flow?”** The main RQ is examined through three supporting RQs, each of which is examined in an individual publication:

1. How does takt production contribute to construction production flow?
Because takt production research has primarily focused on reporting the success of individual case studies, attempts to holistically and critically analyze how takt production affects production flow have remained scarce. To answer this supporting RQ, a theoretical model is built to explain how takt production affects production flow. Theoretical models allow a systematic assessment of a phenomenon, providing the grounds for further research and more structured and predictable implementation of takt production.

2. (a) How do decentralization/centralization affect construction PP&C practices when considering both the production crew and manager perspectives? and (b) Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?

Decentralized, autonomous decision-making has been identified as a potential way to improve construction PP&C practices. However, the topic has been scarcely investigated, and the perspectives of production crews and first-line workers have been missing in the research. To answer this supporting RQ, a multi-method investigation is conducted on how production crews and managers view different PP&C practices. Moreover, suggestions are formulated on how to improve PP&C practices by considering these viewpoints and the possibilities of both decentralized and centralized decision-making.

3. How to improve construction PP&C practices and production flow by combining takt production and decentralized decision-making?

Both takt production and decentralized decision-making have the potential to improve construction PP&C practices and production flow. However, previous takt production or decentralized PP&C implementations have not effectively considered first-line workers. Meanwhile, takt production implementations have reported that better worker involvement and implementation of more decentralized decision-making could yield improvement in performance. Therefore, combining takt production with decentralized decision-making and involving first-line workers in the process is a potential way to improve PP&C practices. To answer this supporting RQ, a decentralized takt production framework (that is based on the knowledge acquired in answering supporting RQs 1 and 2) is formulated, implemented, and validated.

**Research design** concerns the overarching approach for a study—especially concerning the data collection and analysis process—so that the entity answers the research questions meaningfully and logically (Bryman and Bell 2003). Appropriate research design is critical for bridging the gap between research philosophy and individual methodological decisions (Dainty 2008). This dissertation’s research strategy is primarily based on a **qualitative case study approach**. Case studies fit well for answering “how” and “why” research questions (Yin 2014) and are suitable for a holistic exploration of complex phenomena (Flyvbjerg 2006). Moreover, case studies allow for drawing concise boundaries
for exploring PP&C practices in the project production context, providing an opportunity to gain detailed and extensive information with the narrative element.

The rest of the dissertation is structured as follows: Chapter two (Theoretical background) presents the relevant literature related to production flow, construction PP&C practices and takt production, and decentralized decision-making. Chapter three (Research philosophy and methods) presents the research philosophy and a detailed description of the research methods used. Chapter four (Summary of the findings) summarizes the publication results and their main contribution. Chapter five (Discussion) synthesizes the theoretical and practical contributions, discusses study reliability, validity, and limitations, and provides suggestions for future research.
2. Theoretical background

This chapter has four parts. The first part describes how flow occurs in construction production, along with how good flow is achieved. The second part covers the development of construction PP&C approaches, which is followed by the peculiarities of takt production and its implementation. The third part concerns the role and potential of decentralized decision-making in the construction PP&C context, also addressing its benefits, disadvantages, drivers, and suitability for takt production. Finally, a brief summary of the chapter is provided.

2.1 Flow in construction production

2.1.1 Process and operations flow

As described in the introduction, production flow can be represented as a journey of transforming materials into products through performing value-adding (and non-value-adding) activities (Rother et al. 2003). With a simplified conceptualization, such flow can be divided into two interdependent streams: process and operations flow (Shingo and Dillon 1989). In manufacturing, process flow occurs along the production line, where materials are transferred to products as they move from one work station to another. In contrast, operations flow occurs at production stations, where repetitive activities are performed to conduct the individual transformation steps. However, in the context of construction production, these flows occur differently. The product (such as an apartment) remains still, and production crews move along to conduct individual activities, such as building drywalls or installing piping.

Sacks (2016) proposed a conceptualization for construction production flow that was inspired by Shingo and Dillon (1989), in which the construction process flow comprises the sequence of activities performed for a single product (location). In contrast, operations flow comprises a single repeated activity performed by a single production crew as they move through the locations. This conceptualization is illustrated in Figure 1. In addition to products being processed, locations also serve other multiple, continuously changing purposes, such as work stations, preparation stations, and material storage stations, highlighting the importance of location utilization management in enabling flow (Kenley and Seppänen 2010).
Sacks (2016) proposed a list of conditions for good construction production flow, accounting for eight process (P) and two operations flow (O) conditions:

1. **P1** (process flow condition 1): The variation (and variability) of takt times across locations is minimized.
2. **P2**: The batch size (the number of locations occupied by a production crew) is minimized.
3. **P3**: The sum of time buffers between activities is minimized.
4. **P4**: The number of unnecessary activities is minimized.
5. **P5**: The amount of re-entrant flow\(^1\) is minimized.
6. **P6**: The amount of rework is minimized.
7. **P7**: The amount of making-do\(^2\) is minimized.
8. **P8**: The amount of WIP is minimized.
9. **O1** (operations flow condition 1): The variation (and variability) in each production crew’s takt time is minimized.
10. **O2**: Set-up, inspection, and non-value-adding times are minimized.

The key elements in achieving good flow conditions consist of minimizing non-value-adding activities and reducing variability. Variability denotes how much

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\(^1\) Re-entrant flow refers to an instance in which a production crew re-enters a location multiple times at different process stages (Brodetskaia et al. 2013).

\(^2\) Making-do refers to an instance in which an activity is started or continued with missing prerequisites (e.g., design and process information, materials, space, labor, equipment, or external conditions; Koskela 2004)
production metrics (such as activity duration) can deviate from the desired amount—a high level of variability results in production unevenness and uncertainty that can reduce the quality of both process and operations flow (Hopp and Spearman 2011). Construction production is especially prone to high variability because of, for example, a large number of interdependent project stakeholders and high degree of work conducted at temporary site conditions (Koskela and Vrijhoef 2000, Paez et al. 2005).

In addition to removing variability, the adverse effects of variability can be cushioned by adding buffers (Hopp and Spearman 2011). As in any production, three different buffer types can be identified: time, inventory, and capacity. Notably, these buffer categories can be sorted in varied ways (e.g., Frandson et al. 2015 introduced location buffer as a separate buffer category), but here, the well-acknowledged categorization by Hopp and Spearman (2011) is followed.

**A time buffer** denotes a deliberate lag between activities, preventing production crews from accidentally occupying a location simultaneously (Hopp and Spearman 2011). Time buffers are especially useful in complex projects that have a large amount of uncertainty, and they help to avoid production crews waiting. However, time buffers increase production duration and decrease the utilization rate of locations (Horman and Thomas 2005). Time buffers can also be added in the form of location buffers (e.g., allowing empty locations between activities; Frandson et al. 2015). In construction, time buffers are often the most commonly used buffer type (Ballard and Howell 1998).

**A capacity buffer** denotes the additional resources (e.g., labor) that exceed the minimum amount needed to complete an activity (Hopp and Spearman 2011). Capacity buffers allow for a flexible adjustment to variability without the need to increase project duration (Horman and Thomas 2005). In addition, excess capacity can be used for supporting activities, such as quality inspections, preparing upcoming activities, and continuous improvement (Tommelein 2020). However, capacity buffers result in increased resource needs and costs; in construction, capacity buffers are often avoided because of this increase.

**An inventory buffer** denotes providing resources (such as materials) or conducting work in larger batches than what is necessary (Hopp and Spearman 2011). Inventory buffers allow for more flexibility in conducting work while preventing material or equipment shortages; however, they also result in increased production duration, suboptimal use of locations (occupied by workers or materials), and excess WIP. In construction, an additional form of inventory buffer, plan buffer (Frandson et al. 2015), denotes activities in unscheduled locations that can be done in spare time, also called “workable backlog.” As time buffers, inventory buffers are commonly used in construction, because they cushion production crews from waiting and do not increase direct costs (Horman 2000).

As seen in these descriptions, buffers paradoxically improve (e.g., by removing waiting time for production crews) and decrease (e.g., by increasing production duration) flow simultaneously; thus, buffers should be cautiously implemented during the PP&C process. Because variability comes in different forms and projects have unique needs and constraints, the (combined) employment of buffers
should be determined case by case in the production planning phase and adjusted as needed in the control phase. However, buffers are typically used in the PP&C process without much analysis of their adverse effects. In particular, time (Ballard and Howell 1998) and inventory (Dlouhy et al. 2019) buffers are often used excessively to ensure resource efficiency, but at the same time, they sacrifice process flow. The excess use of time and inventory buffers also hinder the ability to see and remove non-value-adding activities and variability, along with the possibility of improving production. Horman and Kenley (1998) suggest that critically examining the need for time and inventory buffers and substituting them with capacity buffers, where possible, could offer avenues for better flow and continuous improvement that can have long-term positive impacts. Bourgeois (1981) also suggest that capacity buffers can allow the organization (or project) to adapt in uncertain situations while maintaining the capability for innovation. Deliberate use of capacity buffers is also one of the core procedures of Toyota Production System and lean manufacturing (e.g., Liker 2005) in order to achieve increased production reliability without increasing inventory.

2.2 Construction PP&C approaches and takt production peculiarities

2.2.1 Development of construction PP&C approaches

Construction PP&C has long relied on the so-called activity-based approaches, which are based on determining the activities that are necessary to complete the project and their dependencies through a work breakdown structure (WBS). Activity-based approaches plan the project to be completed as effectively and quickly as possible while considering activity attributes such as dependencies, resource needs, durations, and external milestones.

One of the most widely used approaches in the project management context is CPM, introduced by Kelley and Walker in the 1950s (Kelley and Walker 1959). Koskela et al. (2014) suggests that CPM could even be considered “the most important innovation in construction management in the 20th century” (p. 27). In CPM, the activities and their attributes are modeled as a topological network, forming a representation of the project context that can be planned and executed in an optimized way (Kelley and Walker 1959). Indeed, CPM has proven useful in the project management context, for example, in managing contractual and financial components (Koskela et al. 2014).

However, the activity-based methods, particularly CPM, have been criticized for their ineffectiveness when it comes to supporting the management of production (Olivieri et al. 2019) due to multiple reasons: CPM does not consider the use of locations as a resource (Dallasega et al. 2021), results in conducting plans that are complicated and impractical to control (thus providing “very limited use for site management”, Peer 1974, p. 203), and separates decision-making from action (Koskela and Howell 2001). Moreover, Koskela and Howell (2001) along Laufer and Tucker (1987) argue that as the viewpoint of production control is overlooked, managers are obliged to focus on writing reports and explaining what went wrong rather than tackling future problems. Despite its
shortcomings, CPM is still a widely used PP&C approach, especially by contractors and clients (Alves et al. 2020).

Location-based approaches have been developed and implemented to overcome the shortcomings of activity-based approaches. In addition to WBS, they also identify a location breakdown structure (LBS) that allows for planning and controlling the utilization of locations and improving production flow (Kenley and Seppänen 2010). The detailed documentation of location-based approaches began in the mid-1900s, when Lumsden (1968) and Peer (1974) introduced the **line of balance** (LOB), which plans for uninterrupted operations flow and is especially suited for projects containing a large amount of repetitive or linear work (Arditi et al. 2002). This development was followed by Mohr (1979), who introduced the flowline method for visually representing the operations flow, and Russell and Wong (1993), who integrated LOB and CPM planning logic to allow location-based approaches to be extended to projects with nonrepetitive work. Continuing this development, Kenley and Seppänen (2010) were the first to deliberately consider the control component in location-based PP&C approaches through their development of **LBMS**. LBMS aims for good operations flow and continuous resource utilization through production planning, which is supported by simulating different planning scenarios. LBMS also aims to proactively control production aided by tracking and forecasting the production progress (Seppänen 2009).

Another approach that deliberately aims to support production management, **LPS**, should also be mentioned in the context of PP&C approaches. LPS was developed in the early 1990s (Ballard and Howell 1994) and has been extensively studied and implemented in lean construction research and practice. LPS was founded on the idea of conducting planning & control in converging horizons (master planning, phase planning, lookahead planning, weekly work planning, and learning), in which the level of detail increases as the execution of work nears. To ensure plan stability and predictability, LPS focuses on revealing and removing the constraints for work, making reliable promises by the planners to ensure plan commitment, ensuring that the work is reliably handed over from one production crew to another, and ensuring continuous improvement (Ballard et al. 2009). One key component of LPS is the involvement of the managers nearest to the site, the “last planners,” in the collaborative process to further improve production crew commitment and plan reliability (Ballard 2000).

These approaches are not exclusive but instead share characteristics (e.g., location-based methods often make use of WBS similar to activity-based methods), and they can be used simultaneously or in combination to support each other’s shortcomings. For example, Seppänen et al. (2010) have suggested that combining LBMS with LPS can provide elevated results when the systematic, data-based planning and forecasting of LBMS is used to provide a way for structuring work (e.g., Tsao 2004), hence feeding the collaborative decision-making and root cause analysis of the LPS process.
2.2.2 Peculiarities of takt production

The development of takt production can be seen as a continuum of the evolution of location-based approaches and LPS. Similar to the presented location-based approaches, such as LBMS, takt production aims to form a production plan based on the identified WBS, LBS, and related activity attributes. The plan is then controlled and improved to maintain good flow (e.g., Frandson et al. 2013). In addition, the overarching takt production process resembles LPS planning & control horizons (see, e.g., TPTC three planning & control levels introduced by Dlouhy et al. 2016).

However, differences also exist. Previous location-based approaches have primarily considered enabling good operations flow (visualized with flowlines) by focusing on the continuous utilization of resources and offering stable resourcing for production crews by employing extensive time and inventory buffers (Frandson et al. 2015). In contrast, takt production prefers capacity buffers, hence maintaining a constant takt time of activities, producing timely and reliable handoffs between production crews, and creating good production flow holistically (Frandson 2019). Linnik et al. (2013) elaborate on this difference by illustrating that approaches focused on operations flow aim to minimize “workers waiting for work,” while takt production also simultaneously aims to minimize “work waiting for workers.” Maintaining a constant takt time also allows further standardization of activities, material deliveries, and the use of locations (e.g., Binninger et al. 2018).

Thus, takt production better considers all 10 elements of good flow (Sacks 2016). Even though using capacity buffers might occasionally reduce crews’ resource efficiency, the long-term overall effects have been argued to be positive as the process flow improves (Horman 2000). As a most distinct result, the lesser use of time buffers leads to decreased production durations (Linnik et al. 2013). Also, even though not necessarily required, smaller batch sizes characterize takt production implementation because smaller inventory buffers are often used (e.g., Binninger et al. 2018). Small batch sizes enable a better adjustment of the production speed, reduce variation between activities, and better identification of improvement opportunities; however, they can also result in resource fluctuation and increase non-value-adding activities (Alhava et al. 2019), especially in projects with high amounts of nonrepetitive work (Tommelein 2017).

2.2.3 Takt production implementation process

The overarching structure of the takt production implementation process shares similarities with the converging planning & control horizons of LPS. Some authors, such as Frandson et al. (2015) and Ballard and Tommelein (2021), suggest that takt production works best when combined with the LPS process, providing a similar counterpart as LBMS in terms of structuring work. Some authors, such as Dlouhy et al. (2016), see takt production as a standalone system that possesses an inherent overarching structure of planning & control horizons. Nevertheless, the takt production implementation process generally follows
Theoretical background

three steps, structured like what is often used to describe PP&C process implementation (Brodetskaia et al. 2013): takt planning (high-level and detailed), takt control, and continuous improvement.

**High-level and detailed takt planning**

Takt planning aims to create a production plan that employs good flow (Linnik et al. 2013) while addressing the goals of the project and client (Dlouhy et al. 2016). High-level takt planning focuses on building the overall structure of the plan. First, the data, such as the requirements and preconditions for production (e.g., activities and their workloads, preferred WBS and LBS, preferred direction of flows, available resources, and milestones), are collected to form the basis for planning (Frandson et al. 2013). Data collection can continue through the planning phase as new information arises and new project participants are integrated into the project (e.g., Tommelein 2017). High-level takt planning results in a rough plan that forms the basis for the production strategy and for further, more detailed plan development (Ballard and Tommelein 2021).

Detailed takt planning focuses on iteratively determining takt time, takt areas (a location that a production crew occupies for a duration of takt time), wagon contents (a batch of activities that are completed within a takt time in a specific takt area), takt trains (a sequence of wagons that forms the process flow) and the allocation of resources (Binninger et al. 2017a). Iterating these parameters allows for a flexible way of forming a detailed takt plan, hence offering avenues for plan optimization (including noticing and removing variability and non-value-adding activities; Frandson 2019) with both repetitive and nonrepetitive work scopes (Tommelein 2017). In the context of a single train (and the absence of time buffers), the relation between overall duration, number of wagons, number of takt areas, and takt time can be determined through a formula (Nezval et al. 1960, as acquired from Binninger et al. 2018):

\[
\text{Overall duration} = (\text{number of wagons} + \text{number of takt areas} - 1) \times \text{takt time} \quad (1)
\]

Furthermore, the takt plan can be balanced and the variability be taken into account by introducing buffers into the plan. As a rule of thumb, Frandson et al. (2015) suggest loading wagons for 70–80% of their maximum capacity, and Dlouhy et al. (2019) suggest reserving additional time buffers at the end of the schedule that can be utilized between wagons during takt control, as needed. The manipulation of batch size also allows for more flexibility to inventory buffering, and reducing the batch size decreases the overall duration without increasing resourcing (Formula 1). However, small time and inventory buffers require timely coordination of the site and supporting activities (such as logistics management; Tetik et al. 2019) that should match the interval of the batch size and takt time, which might result in increased (managerial) effort (Haghsheno et al. 2016).
**Theoretical background**

* **Takt control**

Takt control ensures that the production progress is monitored and steered to proceed with the takt plan or that the plan is adjusted when changes are needed. Takt control is based on timely, rhythmic, visual production control (Frandson et al. 2015), with a particular effort on proactive quality control and providing reliable wagon handoffs for trades (Dlouhy et al. 2016). Takt control makes use of similar tools as the LPS: short stand-up meetings (daily huddles), physical or digital visual tools to ensure situational awareness and mutual understanding of the production progress for all the stakeholders (for the site crew, but also for the providers of supporting functions, such as material operators and designers), and the measurement of progress data that can provide a basis for collaborative root cause analysis and supports learning (Frandson et al. 2014). It has been suggested that the set of possible adjustment actions (such as adjusting the planning parameters or introducing or removing buffers) be predetermined and then collaboratively implemented as needed (Binninger et al. 2017b). Takt control is carried out throughout the whole production and begins with a “ramp-up” phase in which the initial issues (identified when the production begins but were unforeseen during the planning) are solved, and the production pace, based on takt time, is set. The ramp-up phase can also be conducted at a slower pace to ensure adequate time for solving the initial issues, hence preventing them from cascading immediately.

* **Continuous improvement**

Concurrently and after takt planning and takt control stages, problems and improvement avenues are proactively identified and used for learning (e.g., using root cause analysis techniques) and further employed to conduct continuous improvement. Because takt production makes these problems and improvement avenues largely visible while creating an urgency to solve them (e.g., Frandson et al. 2013), continuous improvement is a central part of the takt implementation process that enables an improvement of flow in both the short (within projects) and long term (over projects). To be effective, continuous improvement needs particular attention and can possibly increase resources (which, however, that can be partially acquired from the implemented capacity buffers; Horman and Kenley 1998).

Next, we take a look at decentralized decision-making, another novel approach for improving construction PP&C practices.

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3 Situational awareness considers how various stakeholders perceive and understand the status of different components through time and locations in dynamic systems (Endsley 1995), such as construction production.
2.3 Role and potential of decentralized decision-making in construction PP&C

2.3.1 Philosophical underpinnings of decentralized decision-making

Since the mid-1990s, the development of engineering (and construction) management and decision-making practices has been dominated by the Platonian view of the world (Koskela et al. 2019). Introduced by the Greek philosopher Plato (427–347 BCE), this view states that all the required knowledge can be obtained from abstract conceptualizations through deduction and that observations from practice do not need to be considered. This view has formed the foundation for centralized management based on the assumption that managers can independently form a plan that can be put into action by workers without problems. Johnston and Brennan (1996) call this way of managing “management-as-planning” (MaP), which is also akin to the Taylorist practices (Taylor 1947) widely employed in factories throughout the last century. However, scholars have increasingly argued that such perceptions do not provide realistic or practical conceptualization of the world. The effectiveness of management practices in which decision-making and action are separated has been questioned, especially in increasingly complex and networked systems such as construction project production (e.g., Bertelsen 2003, Pollack 2007). Johnston and Brennan (1996) criticize how using only deductive thinking as a source of knowledge to successfully manage production (or, for that matter, any other) systems is a naïve yet widely held and practiced assumption.

To overcome these shortcomings of the Platonian view in managing production systems, Johnston and Brennan (1996) with Koskela et al. (2019) suggest complementing the Platonian view with the Aristotelian view of the world (introduced by a student of Plato, Aristotle, 384–322 BCE). In addition to deduction, the Aristotelian view suggests acquiring knowledge through induction, that is, through empirical observation of real-world events by those participating in the action (Koskela et al. 2019). This view provides the foundations for decentralized management, in which decision-making and action are intertwined rather than separated entities. Johnson and Brennan (1996) call this way of managing “management-as-organizing” (MaO), in which the managers, rather than autocratically making all the decisions, fill the role of facilitators who help the workers succeed in making independent decisions regarding their own work. Koskela and Howell (2002) add that MaO is connected to the language/action perspective (LAP; Winograd 1986). LAP suggests that organizations’ decisions are mostly made through collaboration and commitments between participants, instead of direct commands, hence forming two-way communication and decision-making paths. Johnson and Brennan (1996) further argue that embedding decentralized decision-making into management is necessary for increasingly complex and networked (production) systems that cannot be effectively understood and coordinated by single authorities. In decentralized management, workers are not seen as “cogs in the wheel” but as capable individuals with original ideas and the motivation to plan, control, and improve their work.
2.3.2 Decentralized decision-making in construction PP&C

Following the development of general engineering management, construction PP&C management practices have primarily adapted the Platonian view, resulting in the evolution of centralized practices. Thus, the popular PP&C approaches—such as CPM and LOB—have been built on the assumption of using deductive knowledge acquisition and centralized decision-making. It has been assumed that projects are simple, predictable entities that can be planned and executed as such, orchestrated single-handedly by a planner or site manager (Morris 1994). Here, production crews and workers are treated mainly as executors, with no real need to connect them to the PP&C decision-making undertaken by general contractors (GCs) or the client (e.g., Johansen and Wilson 2006).

However, the idea of deliberately using the inductive knowledge acquirement—employing the Aristotelian view and considering the complex nature of construction projects—gained interest in PP&C management practices starting the late 1990s and early 2000s (e.g., Howell and Ballard 1994, Winch and Kelsey 2005). It has even been suggested that construction production would naturally align toward decentralized rather than centralized management practices (Ben-Alon et al. 2014, Sacks and Harel 2006), with production decisions emerging through the expertise, communication, and actions of production crews, hence forming a dynamically and constantly evolving state (Watkins et al. 2009, Winch and Kelsey 2005). The notions of Coffey (2000) and Schöttle (2020) also support these suggestions; the authors state that construction workers are inherently motivated to take responsibility for decision-making, as long as the needed managerial structures are ensured. Thus, the wide use of the dominating centralized practices should be further questioned in the context of construction PP&C (Bertelsen 2003).

Indeed, PP&C approaches that employ decentralized decision-making have already been developed and implemented in the construction PP&C context. For example, the aforementioned LPS and agile methods, such as scrum (e.g., Owen et al. 2006), have seen increased interest over the past two decades, even though they have not achieved the reputation of being mainstream PP&C approaches. These approaches have put increased effort into the collaborative aspect, providing a structure for how teams and workers make decisions together (Bølviken et al. 2015). However, it should be mentioned that, although the most popular PP&C approaches are not deliberately built on employing decentralized decision-making, they can still be used in such a way. For example, combining CPM and LPS (Huber and Reiser 2003), LBMS and LPS (Seppänen et al. 2010) and takt production and LPS (Frandson et al. 2014) have all demonstrated synergy advantages, providing a suitable way to increase the degree of decentralization by including crew leaders in decision-making. Nevertheless (as already mentioned in the introduction), the presented decentralized approaches could be further improved by taking into account the decision-making power and perceptions of first-line workers, something that has been missing in the previous and current mentioned development and implementation initiatives.
2.3.3 Benefits, disadvantages, and drivers of decentralized decision-making

Decentralized decision-making has shown several benefits in various contexts. In addition to improved organization and project performance, it has demonstrated increased motivation, well-being, sense of ownership over activities, and commitment to goals (Mintzberg et al. 1976, 1983); increased agility and responsiveness to changes (Richardson et al. 2002); increased proactivity and creativity, both in the short and long term (Grant and Ashford 2008); and an improved skill development and ability to solve conflicts (Humphrey et al. 2007, Yang and Guy 2011) of teams and individuals. Thus, decentralized decision-making could be seen as an improvement for the overall project and for individuals’ performance and well-being.

In the construction PP&C context, decentralized decision-making has been specially promoted in lean construction research, for example, through the implementation of LPS (Ballard 2000). It has shown improvements such as reduced variability and non-value-adding activities, improvement plan commitment, and improved production reliability (Priven and Sacks 2015), with increased production progress transparency and increased cost and time performance (Castillo et al. 2018, Formoso and Moura 2009). Teräväinen et al. (2018) also suggest that construction professionals prefer a working environment that embraces autonomy and creativity rather than completely hierarchical decision-making practices.

In contrast, decentralized decision-making has also been shown to have particular disadvantages compared with centralized decision-making. These include a decreased ability for overall risk management (Lanaj et al. 2013), slow information travel and coordination between teams that might result in poor cross-team collaboration (Mintzberg 1983, Stinchcombe and Heimer 1985), and inconsistency and inaccuracy in overall progress tracking (Barber et al. 1999). These disadvantages are especially prone to occur in large organizations (or projects), if the increased autonomy and interdependency of teams and workers—providing an additional layer of complexity—are not effectively addressed (Drazin and Van de Ven 1985, Leavitt 2005).

To overcome these disadvantages, it has been suggested that numerous enabling drivers should be considered during the implementation of decentralized decision-making. As found in the general and construction management literature, three distinct drivers can be identified. First, involving and preparing teams (such as production crews) early and intensively is a key driver for successful decentralized decision-making (Bertelsen and Koskela 2005, Chinowsky et al. 2010, Pikas et al. 2012, Saurin et al. 2013). During successful involvement, the teams’ and workers’ distinct roles and responsibilities should be officially determined, and they should be trained to successfully operate within these roles. Managers should be trained to cope with their role as facilitators rather than work as autocrats. In addition, enough time and resources should be allocated for teams’ and workers’ own decision-making and problem-solving through their participation.
Second, ensuring information transparency and building trust within and between teams has been identified as a key driver for successful decentralized decision-making (Baiden et al. 2006, Chinowsky et al. 2008, Coffey 2000, Howell and Ballard 1998, Kärkkäinen et al. 2019, Loosemore 2014, Martin 2019, Saurin et al. 2013). Adequate transparency and trust create a space for psychological safety in which the participants can express themselves without fear of being blamed or punished. In addition, these drivers increase the commitment to common goals, reducing the need for micromanagement.

Third, providing the basis for broader decentralization, empowering teams and individuals to conduct independent and autonomous decision-making has been identified as a key driver (Bertelsen 2003, Magpili and Pazos 2018, Saurin et al. 2013, Zábojník 2002). Increased autonomy has been seen as resulting in increased plan reliability (Sacks and Harel 2006), increased motivation toward work (Zábojník 2002), increased ability to succeed when something unexpected happens (Desai and Abdelhamid 2012), and increased diversity of perspectives (Saurin et al. 2013).

Finally, it should be mentioned that opting only for decentralized decision-making might not yield the optimal outcome; instead, a context-specific balance between centralized and decentralized decision-making should be the goal (Koskela et al. 2019). For example, a larger proportion of centralization might be needed in large projects and in instances where decentralization drivers have not been previously implemented. The synthesis of the differences between decentralized and centralized decision-making is presented in Figure 2.

Figure 2. Differences between decentralized and centralized decision-making (adapted from Publication 2).
2.3.4 Takt production and decentralized decision-making

Based on the presented literature, it could be hypothesized that decentralized decision-making can offer a suitable counterpart for takt production because it has numerous complementary aspects for PP&C that could be embedded into takt production. These include, for example, considering the decentralization drivers (early involvement and preparation of production crews, ensuring information transparency and building trust, and empowering production crews to conduct independent and autonomous decision-making) in the takt production implementation process. Decentralized decision-making could offer an increased possibility of achieving sound production performance and good flow, in addition to providing ways to support better commitment and well-being of production crews, especially first-line workers.

2.4 Theoretical background summary

In this chapter, three distinct topics were covered: flow in construction production; construction PP&C approaches and the peculiarities of takt production; and the role and potential of decentralized decision-making in construction PP&C.

Inspected through the streams of processes and operations, good production flow can be achieved by considering 10 distinct elements that intertwine with decreasing non-value-adding activities and removing or cushioning variability. Although location-based PP&C approaches have been developed to support production management and increasing production flow, they have mainly focused on good operations flow, with takt production being the first approach to also consider good process flow and a promising candidate for achieving overall high-quality flow. However, a theoretical explanation of how takt production affects production flow, hereby stepping over the effects in individual case studies, has not yet been formulated: this is a gap that will be focused on in the empirical part by answering the supporting RQ1.

Another novel approach for improving construction PP&C practices and flow—decentralized decision-making—has garnered increased interest and achieved promising results in practice regarding PP&C process effectiveness and worker well-being. Evaluating how these promising results surface from the viewpoint of production crews and first-line workers is a knowledge gap that will be further focused on in the empirical part by answering the supporting RQ2.

Finally, while providing benefits independently, decentralized decision-making and takt production could also be combined, possibly resulting in even better outcomes than individual implementations. However, assessing their combined use by involving the first-line workers has not yet been conducted; this is a knowledge gap that will be further focused on in the empirical part through answering the supporting RQ3.

Next, the research design of the present dissertation and of the individual publications that were employed to explore these gaps are presented.
3. Research philosophy and methods

This chapter presents the underlying research philosophy, the research methods used, and a brief discussion of the countermeasures for the possible limitations related to study’s validity and reliability.

3.1 Research philosophy

Research designs are subject to philosophical presumptions (Saunders et al. 2009), which are necessary in understanding which assumptions and stances researchers take in their research. These presumptions can be described with research paradigms (Kuhn 1962) that tie ontological and epistemological assumptions (i.e., the view toward the nature of reality and view toward acceptable knowledge) to the study’s methodological decisions.

In this dissertation, the nature of reality and knowledge is primarily viewed through the paradigm of interpretivism, which is supported by the paradigm of constructivism. In contrast to positivism (a research paradigm that views knowledge as objectively obtained through measurements and statistical analysis), interpretivism presumes that reality and knowledge are socially constructed through individuals’ subjective observations and dialogue, resulting in no single but instead multiple interpretations of the truth that the social structures and culture also shape (Rehman and Alharthi 2016). In interpretivism, knowledge is acquired through making sense of these multiple interpretations while recognizing that the researchers’ personal interpretation (e.g., values, background, and biases) can also affect this dialogue and the result (Creswell 2014). Like interpretivism, constructivism presumes that no single, predetermined, or stationary truth exists—instead, reality and knowledge are constructed and molded constantly through researchers’ interpretations. Guided by interpretivism and constructivism, it is viewed that construction project production forms complex social systems in which contextual interpretation plays a key role in holistically understanding them. Noteworthy here, adopting these paradigms often leads to favoring qualitative research methods.

Interpretivism and constructivism align with the exploratory nature of the present dissertation, which aims to make sense of the selected novel PP&C approaches in their real-life context. Exploratory research is well suited for investigating complex phenomena that have not been extensively studied. Moreover,
Research philosophy and methods

it is suitable for obtaining an elevated understanding and providing fresh insights on novel topics, possibly resulting in more precise future research questions. The current dissertation’s exploratory nature and adoption of interpretivism manifest in creating theoretical models and implementation frameworks, implementation suggestions, and detailed future research suggestions. Noteworthy, the research includes both descriptive (aiming to understand how present attributes, structures, and relationships effect a phenomenon) and prescriptive (aiming to understand how actions or interventions effect on what would happen for a phenomenon) parts. While the supporting RQ 1 and 2(a) are primarily descriptive, the supporting RQ 2(b) and RQ 3 are primarily prescriptive (see also Table 1 below).

For the sake of brevity, the study scope is limited to takt production and decentralized decision-making. The author is aware that, inevitably, there exist other novel approaches that could yield benefits for construction PP&C practices; however, to gain focus, mapping and examining a larger proportion of possible approaches is deliberately left for future research.

3.2 Research methods

In this dissertation, the RQs are examined through individual studies, each of which have been published in a peer-reviewed journal. Table 1 summarizes how the research methods and aims used are connected to the RQs, their related publications, and the collected primary data on which the analysis is based.

Table 1. Research questions, related studies, used research methods, and primary data.

<table>
<thead>
<tr>
<th>Supporting RQ</th>
<th>Related publication</th>
<th>Published in</th>
<th>Methods and study aim</th>
<th>Primary data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How does takt production contribute to construction production flow?</td>
<td>Publication 1. How takt production contributes to construction production flow: a theoretical model</td>
<td>Construction Management and Economics (published 1/2021)</td>
<td>Qualitative multiple-case study (six cases): formulation of a theoretical model.</td>
<td>27 semi-structured interviews, supported by several (&gt;10) site visits, and project document observation.</td>
</tr>
<tr>
<td>2. (a) How do decentralization/centralization affect construction PP&amp;C practices when considering both the production crew and manager perspectives? and (b) Based on the aforementioned perspectives, how may construction PP&amp;C practices overall be improved?</td>
<td>Publication 2. Improving construction management with decentralised production planning &amp; control: exploring the production crew and manager perspectives through a multi-method approach</td>
<td>Construction Management and Economics (published 2/2022).</td>
<td>Multi-method comparative case study (two cases): investigation on used PP&amp;C practices and suggestions on how to improve PP&amp;C practices.</td>
<td>Survey-based social network analysis with 53 survey responses, and 13 semi-structured interviews, supported by 6 site visits, meetings, and project document observation.</td>
</tr>
<tr>
<td>3. How to improve construction PP&amp;C practices and production flow by combining takt production and decentralized decision-making?</td>
<td>Publication 3. Combining decentralization decision-making and takt production in construction planning &amp; control to increase production flow</td>
<td>Frontiers in Built Environment (published 9/2022).</td>
<td>Qualitative single-case study, design science research: formulation, implementation, and validation of a framework.</td>
<td>Facilitation and observation of three production planning sessions, 17 semi-structured interviews, supported by a site visit, meeting and project document observation, and 6 expert workshops.</td>
</tr>
</tbody>
</table>
The research primarily consists of qualitative case studies, with primary data being semi-structured interviews, observation of production, observation of production documentation, and, in the third study, the facilitation of three takt planning sessions. Additionally, survey-based social network analysis (SNA) and design science research (DSR) approaches with expert workshops are used in publications two and three, respectively, to support the case study strategy. The primary connection between the descriptive and prescriptive parts of the research is that the results introduced in the first and the second study provide an understanding to solve the problem concerned in the third study, providing a starting point for devising a decentralized takt production implementation framework.

The publications were conducted as individual research efforts; however, in writing this dissertation, the results and derived conclusions have been critically revisited to ensure their alignment with the overall contribution. Therefore, the results in the Findings chapter may slightly alter what is presented in the original studies. Next, the fit of specific methods within the chosen research strategy is further justified, and the data collection and analysis process is described. The specific data sources are presented in the Findings chapter.

3.2.1 Case study

Three different kinds of case studies were utilized to effectively acquire knowledge and address the RQs. In the first publication, a multiple-case study of six cases was used to allow for a broad exploration of the phenomena (Eisenhardt and Graebner 2007), a comparison of varying implementation conditions (e.g., different project types, geographical locations, and maturity of implementation), and generalization of the results, resulting in the opportunity to build a theoretical model for how takt production contributes to production flow. In the second publication, a comparative case study of two cases was used to allow for a comparison of two contrasting viewpoints (centralized versus decentralized approach in PP&C), allowing to draw conclusions on their effects (Seawright and Gerring 2008) and provide suggestions for PP&C improvement. In the third publication, a single-case study was used for focus and depth. According to Tel- lis, single-case studies are particularly useful in examining “revelatory cases where an observer may have access to a phenomenon that was previously inaccessible” (1997, p. 3), providing the grounds to meaningfully explore the use of the formulated decentralized takt production framework.

Case selection process

Common to all the case studies, the information-rich cases with the availability of meaningful information (Creswell and Clark 2017), including the possibility of conducting interviews and accessing project observation and documentation, were preferred in the final case selection after the below-presented criteria had been satisfied.

In the first and the second publications, the case selection process was carried out by mapping the potential cases by contacting and interviewing construction
management experts, GCs, and client representatives to identify cases satisfying the set study criteria. In the first publication examining how takt production contributes to production flow, the case selection was based on three conditions: (1) takt production was implemented in the interior phase of the case project (to allow better comparability between the cases); (2) the selection covered case projects with both repetitive and nonrepetitive work (to allow for a comparison between such project types); and (3) the selection covered case projects with varying maturities of implementation (to allow for a comparison of the effect between cases with no previous experience, some experience, or high experience with takt production). In the second publication that examined how decentralization/centralization can affect construction PP&C practices, the case selection was based on two conditions: (1) the selection covered both centralized and decentralized approaches to PP&C decision-making (to allow comparison between such approaches), and (2) the selection allowed for inspecting production decision-making and information flow holistically but also in inspecting specific tasks, here considered as embedded subcases.

In the third publication examining how combining takt production with decentralized decision-making affects construction PP&C practices and production flow, the case study was identified through the participants in the expert workshops (described later in this chapter). The case selection was based on two conditions: (1) the ability and willingness to adopt the framework (to ensure successful implementation and an evaluation of the formulated decentralized takt production framework) and (2) access comprehensive data collection, including the possibility of participating in facilitating the takt planning sessions and access for several rounds of interviews.

*Primary data collection: semi-structured interviews*

All three case studies (consisting of a total of nine cases) used a similar approach to the semi-structured interviews, which were the primary data collection method within the studies. In total, 57 semi-structured interviews (27 in the first publication, 13 in the second publication, and 17 in the third publication) were conducted. Semi-structured interviews were utilized to gain first-hand information on the topic, allowing the informants to freely reflect on and express their experiences while guiding information toward the research questions. In addition to the researchers taking notes during the interview, the interviews were recorded and transcribed, whenever possible. In the second publication, quotes (which were used to illustrate the opinions of interviewees) were translated from the transcriptions from Finnish to English, with slight editing for clarity. The interviews were primarily conducted in person (45 out of 57), but because of the COVID-19 pandemic, the last 12 interviews for Publication 3 were conducted virtually.

The three case studies utilized different approaches for interviewee selection. In the first publication, the interviewees were selected by identifying the key project personnel participating in the takt production implementation, which was further supported by snowball sampling of additional interviewees from the previous interviews. In the second and third publications, the interviewees were
selected to cover two categories: managers and production crew representatives (namely crew leaders and first-line workers) as a way to gain diverse (and in the second publication, also contrasting) viewpoints toward PP&C practices. In addition, in the second publication, the interviewee selection process was guided by the initially formed social networks (see the next subchapter).

Because the data were often collected and analyzed by multiple authors (see the Authors’ contribution chapter), standardized case description forms were constructed for all studies as a way to enable comparability of the cases, open communication between authors during the data collection, and serve as a basis for structured data analysis. The forms guided the structuring of the data into second-order (e.g., takt planning process or propositions on effects on flow) and first-order (e.g., the effect of workers’ involvement in successful takt control) themes. In addition, general project information formed its own second-order theme. These forms also guided the structure of the interview questions and supporting data collection. The initial structure of the forms was decided during the research design process and, in terms of new information arising, was collaboratively iterated during the data collection and analysis where needed.

Supporting data collection

Data triangulation (Denzin 1978) was employed to increase study validity and generalizability. The supporting data were collected from three distinct sources: (1) observation of production (site visits and site meetings), (2) observation of production documentation (meeting minutes, schedules, contracts, site layouts, production control process descriptions, logistic plans, production organization charts, resource tracking and cost data, and project diaries), and (3) facilitation of three takt planning sessions in Publication 3, in which the researchers trained and provided guidance in adopting the decentralized takt production framework while also collecting schedule and observational data. The supporting data were structured similarly as the interview data.

3.2.2 Social network analysis (second publication)

In the second publication, in addition to semi-structured interviews, SNA was utilized as another primary research method to gain a more holistic understanding of the phenomenon under examination. SNA is well suited for objectively making sense of communication and decision-making structures and providing results numerically and visually (e.g., Chinowsky et al. 2008). Thus, SNA provided a way to meaningfully triangulate the other case study results to holistically understand how the (de)centralization of PP&C affects production communication and decision-making, along with how PP&C practices could be most effectively improved (Poleacovschi et al. 2017, Priven and Sacks 2015). Although SNA possesses certain quantitative aspects, it fits in our interpretivism paradigm because it seeks to make sense of the surrounding social environment through an interpretation of individuals (the SNA data were collected through surveys, see description below) and the use visual and narrative elements of the networks in bringing understanding (Dobbie et al. 2018).
The SNA data collection mimicked Chinowsky et al.’s (2010) two-step process. First, the relevant actors of the social networks under inspection (in this case, project participants directly or indirectly participating in PP&C) were identified. This was done by analyzing project documentation (such as organizational charts) and an identification interview with an actor (e.g., a project manager) who comprehensively understood the PP&C process and involved participants. The identification interview included questions such as “Which project participants are relevant for the production at the moment?” and “Which project participants are relevant for the [specific task] at the moment?” The interview provided a basis for forming the initial social networks, supporting the identification of the interviewees for the semi-structured interviews and engaging relevant actors for the second step: primary data collection performed through a survey.

The survey participants, including all the identified actors directly or indirectly participating in PP&C, were asked to list their recent communication and decision-making patterns (including intensity and modes of communication, e.g., email, face to face, and meeting) for the entire project and the specified tasks (presented in the Findings). The survey consisted of five sections: (i) general information regarding the participant, (ii) questions about general communication, (iii) questions about decision-making, (iv) questions about decision-making around the specific tasks, and (v) open-ended questions about decision-making (to broaden and support the interview data). The questions were structured in free-recall and free-choice format. Out of the 68 actors identified in the two cases, 53 completed the survey, resulting in a 78% response rate. However, during the data collection, some of the actors were perceived as not having a connection to the PP&C process (e.g., sales personnel who had not been part of the project for several months). Thus, the authors felt that SNA could be adequately performed without getting responses from these actors. It was ensured that all actors considered relevant participated in the survey.

The survey results were pseudonymized and combined in Excel to guide the data analysis. Based on the combined data, three types of social network models were constructed: (1) information flow networks (yielding insights on general communication), (2) decision-making networks (yielding insights on decision-making and power structures), and (3) task-specific decision-making networks. In the first and the second network, the unit of analysis was the whole production PP&C context. In contrast, in the third network, the unit of analysis was the specific work task, which helped deepen the understanding of the production teams’ internal dynamics. Gephi (version 0.9.2) was used to construct the networks and their visualizations.

3.2.3 Design science research and expert workshops (third publication)

DSR was applied in the third publication, being built around a single-case study. DSR allowed for an in-depth inspection of the combination of takt production and decentralized decision-making, fitting well with the study's aim because there was no readily available framework for implementing takt production with decentralized decision-making that would also consider the involvement of the
first-line workers. Holmström et al. (2009) elaborate that, in DSR, with it being a constructive process, the researcher actively seeks to solve the identified problem (that can be scientific but also practical) and possibly participates in the action, providing an in-depth inspection of the phenomenon at hand. Mimicked by the approach of Kuechler and Vaishnavi (2008), the DSR was structured around four phases: (1) problem definition, (2) formulation of a decentralized takt production framework and case study preparation, (3) implementation and validation of the framework (that was intertwined with the case study), and (4) discussion of the findings and formulation of the study conclusions.

In addition to the single-case study, six expert workshops were embedded into the DSR process to support the framework formulation, case preparation and selection, along with validation of the framework implementation results. Workshops, consisting of interactive discussions between researchers and domain experts, are suitable for acquiring feedback on novel or scarcely studied phenomena such as process innovations (e.g., Thoring et al. 2020). In our study, the expert workshop consisted of approximately 30 experts (with domain knowledge of construction management and an interest in PP&C development) who were representatives of GCs, construction management consultants, design consultants, trade contractors, and software developers. The study authors acted as facilitators and participated in the discussions that were employed to acquire feedback from the framework and its implementation. The workshops lasted between 30 and 60 minutes, in which the feedback was collected through the authors taking notes and web-based interaction software. Workshops 1 and 2 were live sessions, and the rest of the sessions were conducted virtually because of the COVID-19 pandemic.

3.2.4 Data analysis

In all the studies, the data were analyzed with primarily qualitative means that progressed through narrative development (Miles and Huberman 1994), with the exception of the SNA process, in which the social networks were constructed and partially analyzed numerically. First, the initial data analyses were conducted by the first author, who compiled and structured the data sets to guide further collaborative analysis. The data were structured around the inspected second-order and first-order themes (similar to the case study and interview process) and interpreted by identifying the similarities, differences, and recurring or emerging (sub)themes between different data sources.

The data structuring and analysis were first conducted within cases (resulting in extensive case reports to guide further analysis) and in the instance of multiple cases, followed by an analysis between cases (first and second publication). In the second publication, the social networks and interviews (with supporting case data) were first analyzed separately and case by case, allowing to find similarities and contrasting points between data sources and cases.

After the initial analyses and data structuring, detailed analyses were conducted together with all the authors in all publications. Similar to the initial analyses, the data were further analyzed by identifying similarities, differences, and recurring or emerging (sub)themes. In addition to systematically analyzing

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27
the structured data, the original data were also inspected in an ad hoc manner to allow for intuitive and subjective findings to surface. In the third publication, the collaborative analysis was conducted reciprocally through the DSR process to continuously improve the framework based on the information found.

After the analyses, the results were synthesized in light of the previous literature to form the study contributions, limitations, and suggestions for future research. Notably, a similar line of analysis and synthesis was followed in the compilation part of the dissertation, with the difference being that the author carried out the entire process. The dissertation supervisor and advisor participated by commenting on and providing feedback at the end stages of the analysis and synthesis process.

### 3.3 Countermeasures for limitations related to validity and reliability

Finally, a short discussion is provided on the possible methodological limitations—primarily related to study validity and reliability—and the countermeasures that were taken to tackle them. Study validity indicates the study’s capacity to provide accurate results on the subject the study was set to measure, while reliability indicates the degree of consistency of the measurements and reproducibility of the results (Hirsjärvi et al. 2014).

In qualitative case study research, high validity and reliability are often hard to acquire because of, for example, the subjective nature of research and challenges in demonstrating causality (Yin 2014). Case studies possess limitations in generalizability because of the limited number of data points and high number of variables (such as ones generated by different project settings) (Flyvbjerg 2006, Yin 2014). In addition, the semi-structured interviews (and the free-recall and free-choice format surveys used in the SNA) possess barriers to achieving high reliability because of, for example, possible biases of researchers and study participants and because of possible misinterpretations of interview questions by the participants (Hirsjärvi and Hurme 2008). Regarding SNA, it should also be noted that the constructed networks provide only a static view of communication and decision-making patterns, hence possessing limitations for generalizability and validity.

To address these possible shortcomings, two categories of countermeasures were employed. First, the structured execution of the data collection and analysis were ensured to improve both the validity and reliability (Janesick 1994). This included constructing and using structured case description forms that were also used in semi-structured interviews, collection of the supporting data, and case analyses, which guided the data collection and analysis toward the RQs. A similar process for data analysis between publications helped align the dissertation’s overall contribution. Moreover, the methods used in parallel with the case studies (SNA, DSR, expert workshops) were based on previously recognized method descriptions, hence increasing their reliability.
Second, three different means of triangulation were used: data, methodological, and investigator triangulation. **Data triangulation** was employed by conducting a relatively large number of interviews with multiple groups of interviewees (managers, production crews, and other project participants, such as takt production experts), supported by a large number and range of supporting data (documents and observation), while investigating multiple cases to provide different samples from different project conditions, project types, and geographies (also increasing the generalizability; Eisenhardt and Graebner 2007). **Methodological triangulation** was employed in the second (SNA) and third (DSR and expert workshops) studies, increasing study validity and generalizability and allowing to obtain alternative perspectives on the RQs at hand. **Investigator triangulation** was employed in all the publications: several individuals collected and analyzed the data to gain more resources for data collection, acquire depth in the (collaborative) analysis, and diminish the possibility of researcher bias. Investigator triangulation was supported by the detailed case descriptions, allowing the authors and research assistants to collect and analyze data collaboratively and systematically.

As a concluding thought, it should be noted that, being rooted in interpretivism, qualitative case studies do not seek similar validity and reliability as quantitative research approaches. Rather, the used research methods support the underpinning research philosophy and design in exploring the complex phenomena at hand while making sense of them in a way that quantitative approaches cannot.

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4 According to Denzin (1978), data triangulation refers to collecting data from different sources, times, and persons; methodology triangulation refers to using multiple methods to collect and analyze data while answering the same RQ(s); and investigator triangulation refers to having multiple researchers participating in the data collection and/or analysis.
4. Summary of the findings

This chapter summarizes the individual publications’ findings and presents the key results by answering the supporting RQs. Noteworthy here is that the findings of the first and second publications provided a basis for the study context of the third publication and formulation of the decentralized takt production framework.

4.1 The first publication, “How takt production contributes to construction production flow: a theoretical model”

4.1.1 Study context

This study aimed to answer the supporting RQ1 “How does takt production contribute to construction production flow?” The study was conducted as a qualitative multiple-case study of six cases from Finland, the USA, Germany, and Brazil to validate five propositions based on a literature review, which were synthesized as a theoretical model. The case information is presented in Table 2. To narrow the focus, the study was limited to the interior phases of the projects.
Table 2. Case descriptions and data sources (adapted from Publication 1).

<table>
<thead>
<tr>
<th>General description of the project</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-story residential building project located in Finland, primarily repetitive areas</td>
<td>8-story residential building project located in Finland, primarily repetitive areas.</td>
<td>5-story residential building located in Germany, primarily repetitive areas</td>
<td>9-story commercial building located in California, USA, primarily non-repetitive areas</td>
<td>6-story hospital/labatory building located in California, USA, primarily non-repetitive areas</td>
<td>Automotive plant located in Brazil, primarily non-repetitive areas.</td>
<td></td>
</tr>
<tr>
<td>The goal of takt production implementation</td>
<td>Radical decrease in production duration, without increasing costs or decreasing quality</td>
<td>Radical decrease in production duration, better production control, increase in quality and decrease in costs</td>
<td>Increased stability, without increasing costs or decreasing quality.</td>
<td>Radical decrease in production duration, increased stability</td>
<td>Radical decrease in production duration, increased stability</td>
<td>Radical decrease in production duration, increased stability and transparency</td>
</tr>
<tr>
<td>Maturity level (previous experience)</td>
<td>Low (No previous experience)</td>
<td>High (Most of the participants were already familiar with takt production)</td>
<td>Medium (Some of the participants were familiar with takt production)</td>
<td>Medium (Some of the participants were familiar with takt production)</td>
<td>Medium to high (Client was very familiar with takt production)</td>
<td></td>
</tr>
<tr>
<td>Collected data</td>
<td>14 semi-structured interviews</td>
<td>3 semi-structured interviews</td>
<td>1 semi-structured interview</td>
<td>4 semi-structured interviews</td>
<td>4 semi-structured interviews</td>
<td>1 semi-structured interview</td>
</tr>
</tbody>
</table>

4.1.2 Proposals on how takt production contributes to flow

The empirical section evaluates five proposals based on the theoretical background, here considering how takt production could contribute to production flow based on the flow conditions of Sacks (2016).

Proposition 1: Takt production improves process flow with detailed planning that utilizes flexible planning parameters and favors capacity buffers. This allows for revealing non-value-adding activities and removing them (process flow condition P4), reducing the variation between activities and takt times (P1), reducing the time buffers and production duration (L3), and reducing “work waiting for workers” and WIP (P8).
Proposition 2: Takt production improves process flow by creating an urgency for make-ready work and timely management of supporting flows (e.g., design, material) because failure to cope with the plan is immediately visible to everyone. This allows for removing the amount of making-do because activity preconditions are improved (P7), allows for the removal of accidental re-entrant flow (P5), and rework (P6) because quality control is proactive and timely.

Proposition 3: Takt production may improve operations flow by increasing transparency, stability, and reliability. This allows for more balanced production rates for the trades (operations flow condition O9) and for removing non-value-adding activities (O10). However, capacity buffering and small batch sizes might result in increased waiting or excess movement of production crews.

Proposition 4: Takt production improves process and operations flow by reinforcing continuous improvement by making problems visible to everyone. This allows collaborative revealing and acting upon problems and improvement needs, with adequate resources that capacity buffering offers.

Proposition 5: To improve flow, takt production requires an increased granular effort that is aligned with batch sizes. This requires an increased effort in planning, control, and continuous improvement, making production vulnerable to disruptions. Reduced batch sizes (P2) are characteristic of takt production but are not necessary.

4.1.3 Key findings

Table 3 summarizes the key findings. Overall, takt production implementation was seen as positively impacting PP&C practices and production flow. In all the cases, the implementation decreased production duration, ranging from a 10% to 50% decrease compared with the initially made plans that had no specific location-based approach. The analysis did not yield any remarkable differences between the takt production methods used: TP and TPTC. Instead, it seemed that the takt planners’ or facilitators’ background and experience played a more distinct role in the implementation procedure and planning decisions.

Takt production implementation was also supported by a use of adjacent concepts. Daily huddles (used in all cases except case 1) were seen to provide a structured approach for problem-solving and direct communication among the production crew. The Big Room concept was used in cases 4 and 5 for increased communication effectiveness between the client, the GC and the trades. Moreover, extended training practices were used in every case in order to better integrate the project participants into the takt production process – in addition, in cases 3, 4, 5, and 6, some form of simulations and/or games were used.
The findings support proposition 1. The planning process with the flexible iteration of planning parameters—including the increased use of capacity buffers—helped achieve good process flow. For cases with low maturity (Cases 1 and 2), the amount of control needed to steer and adjust the predetermined plan came as a surprise for the participants. With increased maturity, this seemed to be a predictable result for the participants.

The findings partially support proposition 2. Takt production allowed, but did not ensure, less rework, re-entrant flow, or making-do. Although re-entrant flow can partially be decreased by better planning of operations, it can also occur due to certain construction methods that takt production does not necessary consider. Remarkably, the amount of making-do was perceived as large in

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**Table 3. Key case findings (adapted from Publication 1).**

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilized method</td>
<td>TTP</td>
<td>Not specified</td>
<td>TPTC</td>
<td>TTP</td>
<td>TTP</td>
<td>TPTC</td>
<td>-</td>
</tr>
<tr>
<td>Takt time</td>
<td>1 day</td>
<td>1 day</td>
<td>5 days</td>
<td>5 days</td>
<td>5 days</td>
<td>5 days</td>
<td>-</td>
</tr>
<tr>
<td>Takt area formulaion</td>
<td>By apartments</td>
<td>By apartments</td>
<td>By work density</td>
<td>By work density</td>
<td>By geometrical zones</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Workable backlog</td>
<td>Common spaces</td>
<td>Common spaces</td>
<td>Common spaces</td>
<td>Vertical areas, shafts</td>
<td>Vertical areas, shafts</td>
<td>Auxiliary plant buildings</td>
<td>-</td>
</tr>
<tr>
<td>Takt control process</td>
<td>Three weekly meetings</td>
<td>Daily huddle</td>
<td>Daily huddle</td>
<td>Daily huddle &amp; Big Room</td>
<td>Daily huddle &amp; Big room</td>
<td>Daily huddle</td>
<td>-</td>
</tr>
<tr>
<td>Realized effects on duration of the interior phase</td>
<td>Decreased from 24 weeks to 18 weeks (-33%)</td>
<td>Decreased from 28 weeks to 25 weeks (-10%)</td>
<td>Decreased from 33 weeks to 23 weeks (-25%)</td>
<td>Decreased from 36 to 24 months (-33%)</td>
<td>Decreased several months (no accurate data)</td>
<td>Decreased from 12 months to 6 months (-50%)</td>
<td>Takt production decreases duration</td>
</tr>
<tr>
<td>Proposition 1</td>
<td>Partially supported; need for flexibility was as a surprise</td>
<td>Partially supported; need for flexibility was as a surprise</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
</tr>
<tr>
<td>Proposition 2</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported; large amount of making-do; pacing of supporting conditions emphasized</td>
<td>Partially supported</td>
</tr>
<tr>
<td>Proposition 3</td>
<td>Not supported</td>
<td>Not supported</td>
<td>Partially supported</td>
<td>Not supported</td>
<td>Partially supported</td>
<td>Not supported</td>
<td>Not supported</td>
</tr>
<tr>
<td>Proposition 4</td>
<td>Partially supported; more time for continuous improvement should be reserved</td>
<td>Partially supported; time for continuous improvement should be reserved</td>
<td>Supported</td>
<td>Partially supported; time for continuous improvement should be reserved</td>
<td>Partially supported; time for continuous improvement should be reserved</td>
<td>Supported</td>
<td>Partially supported</td>
</tr>
<tr>
<td>Proposition 5</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
</tr>
</tbody>
</table>
almost all the cases. A more deliberate effort in quality management and alignment of design and material operations with the takt production process (by synchronizing planning and proactively communicating the production status) are needed to further improve the process flow.

**The findings do not support proposition 3.** Even though the benefits of increased transparency, stability, and reliability exceeded the adverse effects of capacity buffering in the high-maturity cases, the combined effects were perceived as negative in the low-maturity cases. Takt production challenged the production crews to operate in radically different ways, which caused increased stress and unforeseen demands, especially for crew leaders, because they had to put more effort into managing capacity buffers. Better integration of trades into the process should include increased effort on social engagement and alignment of contractual requirements.

**The findings partially support proposition 4.** Takt production did indeed make problems more visible to everyone. However, more deliberate resourcing to act on these problems (within but also after projects) should be ensured, preferably as indicated in the takt plan. Particularly with the low-maturity cases (which also had small batch sizes), the problems were revealed faster than the production crews and managers could address them.

**The findings support proposition 5.** Takt production increased resource needs, especially in terms of increasing the workload of site management and crew leaders and the needed training of the production crews. Even though small batch sizes were present, the batch sizes were correlated with the size and amount of work repetition. In larger projects with more nonrepetitive work, larger batch sizes (and takt time of five days instead of one day) were the preferable production planning choice and seemed to support these cases.

Based on the findings, a theoretical model was constructed, as shown in Figure 3. Takt production consists of three domains that contribute to production flow: takt planning, takt control, and continuous improvement. In addition, the supporting conditions (such as alignment of material flow management) must be satisfied to drive positive effects. In addition to aiming for good flow that is swift and even, takt production aims to meet the project’s and client’s needs. The maturity of the implementation plays a role in achieving the presented effects on flow. With high maturity, the effect on both process and operations flow seems to be primarily positive. In contrast, in the cases with low and medium maturity, the results for operations flow were contradictory because the presented adverse effects were magnified. Increased resourcing for continuous improvement and longitudinal development efforts are needed to reap all possible benefits.
Figure 3. A theoretical model of how takt production contributes to production flow (Publication 1). Reprinted with permission.
4.2 The second publication, “Improving construction management with decentralised production planning & control: exploring the production crew and manager perspectives through a multi-method approach”

4.2.1 Study context

This study aimed to answer the supporting RQ2 “(a) How do decentralization/centralization affect construction PP&C practices when considering both the production crew and manager perspectives? and (b) Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?” For a holistic analysis, the study was conducted as a multi-method comparative case study with quantitative and qualitative methods: survey-based SNA and semi-structured interviews (complemented with supporting production data). The SNA was carried out to provide an understanding of communication and decision-making structures in cases identified as having centralized and, in contrast, decentralized decision-making practices. The interviews were carried out to elucidate the SNA findings and deepen the views of the managers and production team members. To gain depth and breadth in the analysis, the case projects were investigated holistically and complemented with an analysis of specific task contexts (Table 4).

The case information and collected data are presented in Table 4. Two Finnish cases—one commercial renovation project and one roadwork renovation project—were examined in this study. The first can be considered a decentralized project with such managerial and PP&C approaches. In contrast, the second can be considered a centralized project with such managerial and PP&C approaches, providing an opportunity for a comparative evaluation.
### Table 4. Case descriptions and data sources (adapted from Publication 2).

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General description of the project</strong></td>
<td>Commercial, renovation ~ 25,000 sqm, 4 phases Located in Espoo, Finland</td>
</tr>
<tr>
<td><strong>Approach to project management and PPC</strong></td>
<td>Integrated project delivery (IPD) with collaborative and decentralized decision-making / planning &amp; control (Big Room and LPS)</td>
</tr>
<tr>
<td><strong>Tasks related to the inspected crews’ work</strong></td>
<td>Electricity works Ventilation and air conditioning (VAC) works Lock installation Painting (Majority of the work is operated by trade contractors)</td>
</tr>
<tr>
<td><strong>SNA data sources</strong></td>
<td>1 identification interview with site engineer Inspection of project documentation: organizational charts, meeting minutes, contact lists 24 SNA survey responses</td>
</tr>
<tr>
<td><strong>Other data sources</strong></td>
<td>3 site visits, 3 site meeting observations Site meeting minutes Production schedules and organizational charts</td>
</tr>
</tbody>
</table>

### 4.2.2 Key findings

The information flow networks of the cases are presented in Figure 4. In both cases, the site crews seemed to have a certain amount of communication transparency (resulting in increased trust) formed around frequent face-to-face communication through managers and crew leaders. Regarding decision-making, in both cases, the interviewed managers felt having a critical role in successful information flow and being responsible for most of the decisions (especially regarding schedules and management of designs and logistics). The most notable difference between the cases—indicated by the information flow networks and manager interviews—was how the collaboration was initiated. In Case 1 (decentralized decision-making structures), the interviewees underlined the importance of collaborative decision-making and the inclusion of production crews to support managers’ decision-making. In Case 2, the managers were perceived as carrying most of the responsibility at all levels of decision-making.
However, when inspecting the decision-making networks around specific tasks (Figure 5 illustrates the decision-making network of electricity works of Case 1 and pipeworks 1 of Case 2), the above-described roles of managers and production crews shifted. In Case 1, the task-level decision-making was decentralized from managers to crew leaders, and in Case 2, the decision-making was held by all members of production crews, in addition to the managers. These findings were supported by the interviews of production crew members, who felt they had a vast amount of responsibility in the daily and weekly PP&C decisions.
They felt motivated to have this responsibility, attesting to the fact that the managers mostly served as information distributors rather than autocrats.

Nevertheless, the interviewees expressed that having decentralized decision-making structures in PP&C can offer several benefits: transparency within the site and whole supply chain, the ability for proactive conflict resolution, commitment to goals, lowered stress of individuals, and increased schedule performance, which are in line with benefits presented in the theoretical background chapter. In addition, building the decentralization drivers—especially trust, ownership, and autonomy—was seen as beneficial for the PP&C process whenever centralized or decentralized decision-making was favored. Altogether, these drivers and the perceived benefits were expressed as leading to more effi-
cient and process-oriented PP&C practices that are proactively built and sustained, rather than ad hoc problem solving—requiring strong individuals to handle the managerial responsibilities—that seemed to be the practice with centralized decision-making structures.

Interestingly, despite the decentralization of decision-making in Case 1, the implementation did not effectively reach the first-line workers. The SNA findings show that the information flow mostly occurred between managers and crew leaders, and PP&C decision-making was dominated by the crew leaders. This indicates that the current decentralized PP&C practices in construction do not fully consider the internal dynamics of the production crews but are mostly limited to the managerial and crew leader level (the “last planners” in the context of LPS).

Another interesting finding was that, regardless of the amount of intended decentralization, the interviewed production crew members perceived PP&C as dynamic and decentralized, with crew leaders and workers carrying a vast amount of responsibility, especially at the micro-level (weekly and daily) decision-making. In contrast, the interviewed managers perceived PP&C to be mostly hierarchical and centralized, and they felt being responsible for most of the decisions. This indicates a stark contrast to how the nature of production was understood among the different roles.

4.3 The third publication, “Combining decentralized decision-making and takt production in construction planning and control to increase production flow”

4.3.1 Study context

This exploratory study, that was conducted using the DSR approach and built around a single-case study, aimed to answer the supporting RQ3 “How to improve construction PP&C practices and production flow by combining takt production and decentralized decision-making?” The study was built upon the knowledge acquired in the first and second publications, that provided an in-depth understanding regarding the problem addressed in this study. In this study, a decentralized takt production framework was formulated, implemented, and validated through a literature review, facilitation of takt planning sessions, semi-structured interviews, and expert workshops, supported by production tracking data and site observation. The collected data are presented in Table 5. The framework was implemented in a Finnish industrial construction project. The implementation covered an interior phase of a manufacturing plant extension of nearly 10,000 m² of space and primarily targeted mechanical, electrical, and plumbing (MEP) works.
Table 5. The case study and expert workshop data sources (adapted from Publication 3).

| Data sources in the takt planning phase | 3 planning workshops; researchers acted as facilitators  
Takt planning data: schedules, meeting minutes, project diary, workshop observations  
5 semi-structured interviews with crew leaders and workers  
I1: Crew leader, sprinkler installation  
I2: Crew leader, electricity works  
I3: Worker, electricity works  
I4: Crew leader, general MEP works  
I5: Worker, general MEP works |
|——|——|
| Primary data sources in the takt control phase | 5 semi-structured interviews with crew leaders and workers  
I6: Worker, sprinkler installation  
I7: Crew leader, electricity works (same interviewee as in I2)  
I8: Worker, electricity works (same interviewee as in I3)  
I9: Crew leader, general MEP works  
I10: Worker, general MEP works  
7 semi-structured interviews with managers and a client representative  
I11: Project manager, electricity works  
I12: Project manager, sprinkler installation  
I13: Project manager, general MEP works  
I14: Project manager, construction manager consultant  
I15: Project engineer, construction manager consultant  
I16: Site supervisor, construction manager consultant  
I17: Project manager, client |
| Supporting data sources | Resource tracking data, schedule data, cost data, meeting minutes (including tracking of preconditions for / barriers to work), and project diary written by a project manager  
Observation: 1 site visit, participation in 2 production meetings |
| Expert workshops | 6 expert workshops with ~30 representatives of general contractors (GCs), construction management consultants, design consultants, trade contractors, and software developers  
Workshops 1 and 2: Framework formulation feedback and case selection mapping  
Workshops 3–6: Framework implementation feedback and framework validation |

4.3.2 Key findings: decentralized takt production framework formulation, implementation, and validation

The decentralized takt production framework was formulated based on a literature review and expert workshop feedback (workshops 1 and 2) (Table 6). The framework was based on the general takt production implementation process presented in chapter two and on knowledge created in the first two publications. It considers the decentralized decision-making drivers (including integrating first-line workers) and the supporting elements for good process and operations flow.
Table 6. Decentralized takt production framework (adapted from Publication 3).

<table>
<thead>
<tr>
<th>Process step</th>
<th>Decentralization drivers</th>
<th>Contribution to flow</th>
</tr>
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<tbody>
<tr>
<td><strong>1a Data collection and high-level takt planning</strong></td>
<td>Data collection: relevant production data are collected to form a basis for high-level takt planning. Data are gathered from building information models, and productivity databases, labor agreements and are supported by the participants’ personal experience. High-level planning: consists of defining goals and milestones based on the client’s preferences, which allows for determining the initial values for the planning parameters (takt areas, takt time, takt wagons, buffers, resourcing), further resulting in the first iteration of the production plan that sets boundaries for further, more detailed planning. Conducted centrally by a ‘core’ team, including, for example, the general contractors (GCs) project and site managers, client, and possibly trade contractors’ managers.</td>
<td>Centralized decision-making allows for a meaningful overall balance between centralized and decentralized approaches and effectively assessing the overall flow and client’s needs (Koskela et al. 2019, expert workshop feedback). The focus is on initiating good overall flow, especially considering process flow conditions P1–P4 and P8 (Lehtovaara et al. 2021, expert workshop feedback).</td>
</tr>
<tr>
<td><strong>1b Formulation of teams and decentralized takt planning</strong></td>
<td>Formulation of teams: this step begins by the core team forming wagon-based planning teams, which are based on the high-level plan, consisting of trade crew leaders and workers who are part of the work activities within specific wagons. Decentralized takt planning: especially focuses on iterating the process within wagon teams by, for example, iterating task durations and sequence, buffers, and resourcing. The iterated decisions are reflected in the overall takt plan, while the constraints and requirements for other wagons are communicated and solved in collaboration with the core team and other wagon teams. The teams should mutually agree on changes in the planning parameters (takt time, takt areas, wagon sequence task distribution, and buffers). The core team facilitates the process.</td>
<td>Ensures early, gradual, and intense involvement of teams, officially determining their responsibilities in decision-making, and allocating adequate time and resources for decision-making and problem-solving (e.g., Saurin et al. 2013, expert workshop feedback). Initiates trust and transparency among site teams and individuals (e.g. Chinowsky et al. 2010). The focus is on improving operations flow (O1–O2) and ensuring that overall flow is maintained during the decentralized planning (initial discussions and expert workshop feedback).</td>
</tr>
<tr>
<td><strong>2 Production ramp-up and takt control</strong></td>
<td>Production ramp-up: final coordination of takt control procedures is conducted to ensure a smooth start. Control mechanisms (e.g., presented by Binninger et al. 2017b) are adapted for takt control, which are also trained for all participants before production begins. Takt control: consists of short-cycled and visual production management through short progress meetings held every day by the core and site teams, accompanied by systematic quality control (including handoffs between every wagon where the quality defects are issued and preconditions for the next wagon are ensured). The decision-making authority to tackle more minor issues should is held within the decentralized teams, gradually involving other teams and the core team in the decision-making if necessary. The core team facilitates the process.</td>
<td>Empowers teams and individuals for autonomous decision-making in practice and ensures daily communication between site teams and management (e.g., Magpili and Pazos 2018, expert workshop feedback). The focus is to especially ensure flow conditions P5–P7 and O1–O2 while maintaining good overall flow (Lehtovaara et al. 2021).</td>
</tr>
<tr>
<td><strong>3 Continuous improvement and training</strong></td>
<td>Continuous improvement (that aims to tackle emerging problems immediately) and training of the participants (especially trade crew leaders and workers, but also the core team members) should be ensured during planning &amp; control phases and between projects.</td>
<td>To cope with the increased decision-making responsibility, individuals are trained and involved through the planning &amp; control process (e.g., Saurin et al. 2013, expert workshop feedback). Supports maintaining the overall flow (Lehtovaara et al. 2021).</td>
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</table>
The key findings of the implementation (case study) and validation (expert workshops) and their sources are presented in Table 7. The results indicate that decentralized decision-making is well suited to be combined with takt production. Although the project participants had no previous experience with takt production (low-maturity implementation), both process and operations flows were perceived as being improved. Decentralized decision-making seemed to especially support good operations flow, for which the results have been contradictory in previous low-maturity takt production implementation cases with no decentralized decision-making.

Interior phase duration savings of 23% were achieved with the support of the interlaced construction and equipment installation phases, meeting the tight deadline for starting the equipment installation demanded by the client. Time savings of three weeks (duration reduction from 20 to 17 weeks) were achieved with takt planning – also, the interlacing allowed the installation phase to start an additional three weeks earlier, resulting in a total of 6 weeks or 23% of duration reduction. Moreover, trade resourcing remained stable through the implementation. For general MEP works, the tasks were finished with less than expected resource needs, while the resource needs of electricity works were more predictable than usual (with exception of a slight resource increase in the end), offering preconditions for good operations flow. Although a slight cost increase was observed due to the need for aggressive implementation of takt control mechanisms (the need was caused by several external challenges, e.g., material delivery problems due to COVID-19 pandemic), meeting the schedule deadline was perceived to have more weight than slightly increased costs.

The framework was successfully implemented in the takt planning phase; however, the elements of decentralized decision-making were not fully implemented in the takt control phase, resulting in not being able to obtain all the intended benefits. Several challenges and improvement suggestions were also found (Table 7), mainly concerning facilitating adaptation to the new PP&C approach and logistics planning & control.
Table 7. Decentralized takt production framework implementation and validation results (adapted from Publication 3).

<table>
<thead>
<tr>
<th>Implementation positive effects</th>
<th>Challenges and improvement suggestions</th>
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<tr>
<td><strong>1a and 1b Takt planning</strong></td>
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<tr>
<td>The site teams’ knowledge helped improve the plan’s process and operations flows (interviewees I4, I5, I11, I15, I16).</td>
<td>Decentralized decision-making was partially dominated by the crew leaders; better involvement of workers is needed (I2, I6, I16, planning session observation).</td>
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<tr>
<td>The site teams were committed to the formed plan, and both crew leaders and workers (I1, I2, I3, I4) and managers (I11, I12, I13) had adequate resources and time for the preparation of work.</td>
<td>Decentralized planning requires a swift adaptation and absorption of information; even more time and resources for decentralized planning is needed (I2, I11, I16).</td>
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<tr>
<td>The planning process helped the team-building process, increasing transparency and trust between the site personnel (I1, I2, I3); a structured and detailed approach with timely involvement fostered effective and collaborative planning (I13, I15, I16, I17, planning session observation, expert workshop feedback).</td>
<td>The role of logistics planning should be increased in the planning phase (I1, I2, I3, I11, expert workshop feedback).</td>
</tr>
<tr>
<td>Tailored framework for the given situation supported implementation (expert workshop feedback).</td>
<td></td>
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<tr>
<td><strong>2 Takt control and 3 Continuous improvement</strong></td>
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<tr>
<td>Effective collaboration, communication, and problem-solving between managers and crew leaders, especially through weekly meetings (I4, I7, I13, I15).</td>
<td>Lacking the participation of workers in decision-making; more effort is needed on following the decentralized process promptly, ensuring the possibility for participation (I6, I7, I8, I11, I13, I15, meeting minutes and meeting observation, expert workshop feedback).</td>
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<tr>
<td>Adequate involvement and awareness were enabled by the intensive planning process, enabling swift adjustment of the plan, when needed (I11, I13, I13, I17).</td>
<td>Inadequate involvement of workers caused stress for site teams (I3, I4, I5, I6); more resources for onboarding and training of workers were needed to ensure commitment (I16, I17).</td>
</tr>
<tr>
<td>Good production crew social dynamics and positive competition between teams (I16).</td>
<td>The role of logistics control should also be increased in the control phase (I12, I13, expert workshop feedback).</td>
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<tr>
<td><strong>Effects on flow</strong></td>
<td></td>
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<tr>
<td>Process flow: effective production planning, wagon handoffs, and “ready with first-time attitude” helped achieve and maintain a good overall process flow; work was primarily in balance (process flow condition P1); the site teams respected the distribution of takt areas and takt time while primarily operating with the determined batch sizes (P2). This resulted in small WIP (P8) and small time buffers (P3) because the tasks began after the preceding one ended (I7, I15, project diary, meeting minutes).</td>
<td>Process and operations flow: slight deterioration of flow at the beginning and end stages of the interior phase because of the intensity of ramp-up (I2, I16), inadequately adjusted project phase interphases (I4, I5, I6), missing JIT (just-in-time) logistics management (I6, I7, I11), and partial reliance on ad hoc management practices in the final weeks (I11, I13) resulted in partially increased number of unnecessary activities (P4), re-entrant flow (P5), making-do (P7), and set-up times (O2).</td>
</tr>
<tr>
<td>Operations flow: primarily good operations flow (O1 &amp; O2); low amount of waiting, stable resource needs (I2, I3, meeting minutes, resource tracking), and predictable workload (I7, I8, I11, I13).</td>
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This chapter presents the theoretical and practical contributions of the dissertation, study limitations, and suggestions for future research. Altogether, these contributions can spur new discussions on the role, impact, and future of takt production and decentralized decision-making in the context of construction management research and practice.

5.1 Theoretical contribution

The theoretical contribution is structured by first answering and discussing the supporting RQs, followed by answering the main RQ.

Supporting RQ1: How does takt production contribute to construction production flow?

The first central contribution is this dissertation is providing an understanding of the effects that different takt production domains (takt planning, takt control, and continuous improvement) have on production flow, hence supporting takt production implementation and systematically reaping the possible benefits. This effort to assess the effects of takt production implementation on flow has not been previously conducted. The conceptual relation of takt production and flow was especially considered in the first publication, whose main contribution consisted of formulating a theoretical model for examining the effects of flow in the takt production context while simultaneously investigating how implementing takt production affects PP&C practices. Through the above-mentioned three domains and distinct drivers (such as the alignment of material and design flow management), takt production can advance the conditions of good flow. Some of the positive effects can be reaped through immediate and low-maturity implementation (especially regarding process flow), while others require increased maturity and continuous improvement (especially operations flow and some process flow conditions, such as minimized making-do).

The findings in this research indicate that various adverse effects continuously surface during takt production implementation, especially during takt control, in contrast to numerous previous studies that have primarily focused on examining the planning part of takt production and reporting positive implementation effects (e.g., Linnik et al. 2013). However, the emergence of these effects
can provide more benefits than harm, creating an urgency to continuously identify their causes and solve them. Our findings highlight that putting adequate resources and long-term effort into takt control and continuous improvement—which have not been largely considered in previous takt production studies (with some exceptions such as Binninger 2017b)—can produce an elevated opportunity for long-term improvements in flow.

Takt production implementation has been previously mostly driven by the GC; however, the study results among other previous studies suggest that a deeper involvement of other parties in the supply chain, such as clients, contractors, designers, and material suppliers (see also, e.g., Dlouhy et al. 2018) could support reaping the benefits of takt production, support wider flow-creation, and support the implementation of innovations such as industrialized construction (see also, e.g., Chauhan et al. 2018). Such efforts could provide an opportunity for executing production more precisely, removing variability, and increasing the opportunity to decrease batch size and remove buffers, hence further improving flow. Nevertheless, our case results indicate that effective takt control, continuous improvement, and supply chain integration seem hard to implement immediately in the current managerial environment, especially with the first implementation efforts.

Regarding takt planning, the findings of this research highlight that understanding the effects of different planning parameters, such as takt time, takt wagons, takt time, resourcing, and buffers, allows for a more deliberate design of the production system that supports flow, rather than relying on arbitrary decisions (such deliberate decisions could also support acquiring more standardized process, increasing the plan reliability and production predictability). A couple of examples from the first study are presented below. First, the selection of takt time often seems to be based on comfort and previous customs. Although takt production is often characterized by small batch sizes and small takt time (e.g., Binninger et al. 2018)—with benefits such as improved process flow and increased ability to see and tackle problems—with low maturity and a large amount of variation, it might offer counterproductive results. In contrast, planners might also rely on overly large batch sizes for comfort, missing the possibility of allowing non-value-adding activities to emerge, resulting in losing the benefits mentioned above.

Second, our study supports the assumption that the right amount of capacity buffering is critical in ensuring proper flexibility while not overly increasing resource needs and costs (e.g., Horman 2000). Although reducing buffers to a minimum might be tempting in order to achieve improved process flow, it might yield negative results if the workers and overall system are overburdened under too much variability with no cushioning. Thus, instead of using planning parameters as rigid inputs, they should be seen as flexible, iterative, and decided based on the project’s preconditions and requirements. The ability to do so seems to inherently increase with implementation maturity; however, there does not seem to be any barrier to doing so right from the first implementation cases. It should also be highlighted that successfully implementing a novel ap-
proach in the planning phase does not automatically guarantee success in production control and continuous improvement (e.g., Frandson and Tommelein 2016); instead, this requires constant effort throughout the project.

Supporting RQ2: (a) How do decentralization/centralization affect construction PP&C practices when considering both the production crew and manager perspectives? and (b) Based on the aforementioned perspectives, how may construction PP&C practices overall be improved?

The second central contribution of this dissertation is providing an understanding of how a better balance of centralized and decentralized decision-making could support an improvement of construction PP&C practices. Decentralized decision-making on PP&C was particularly examined in the second publication, which indicate that PP&C practices indeed seem to benefit from a starker alignment toward decentralization.

To answer the first part of the research question, our findings support previous research indicating that decentralization can provide a range of benefits in two categories. First, the benefits related to project-level performance include systematic capacity development, improved ability for conflict resolution (also Yang and Guy 2011), and schedule performance (also Castillo et al. 2018). Second, benefits related to worker well-being and performance include increased commitment and communication (Mintzberg et al. 1976, 1983), lower stress, and positive competition between teams (Humphrey et al. 2007). Our findings also reinforce the notions in previous studies that aligning the production system deliberately and proactively toward decentralized decision-making, for example, by involving teams in PP&C processes (Saurin et al. 2013), ensuring information transparency and building trust within and between teams (Chinowsky et al. 2008), and empowering teams and individuals to conduct independent and autonomous decision-making (Bertelsen 2003) seem to support achieving the above-mentioned benefits. Notably, some elements of centralized decision-making inevitably (and preferably) exist even when aiming for increased decentralization, and one should aim for a balance that is adequate for the given project (also Koskela et al. 2019).

The most surprising finding while exploring the possibilities of decentralization was the epistemological difference in how different project participants approached PP&C. Regardless of the degree of decentralization, managers and production crews (crew leaders and workers) seemed to have vastly different views on how PP&C practices emerge during production. While the former perceived PP&C through a Platonian deductive lenses (centralized approach, e.g., Johnston and Brennan 1996), the latter perceived PP&C through Aristotelian inductive lenses (decentralized approach). That is, the managers thought that their plans primarily drove work, while the workers thought that their daily and weekly decisions were the primary drivers for work. This epistemological difference has not been largely explained or explored in previous construction management research, which might be explained by the scarce amount of research inspecting workers’ viewpoints.
Even though future research is needed on the topic, our results provide an indication that misunderstandings in definitions and epistemological differences can cause confusion and missed opportunities for developing PP&C practices. When individuals are not largely aware of those viewpoints other than their own, the formed gap in epistemological understanding can lead to adverse effects, such as missed improvement possibilities, the waste of unused talent, feelings of being overwhelmed, and building of overly centralized PP&C practices that prevent effective implementation of decentralized PP&C (also, e.g., Johansen and Wilson 2006), even though the willingness for change would be otherwise present. When managers are not aware of the daily problems that workers face, the gap between “work-as-imagined” (assumptions on how work is conducted) and “work-as-done” (how work is conducted in practice; Soliman and Saurin 2020) is extended, further magnifying the problems described above. On the contrary, mutually recognizing the differences in altering views of production’s epistemological nature could allow for an understanding of other individuals’ stances and pain points, laying the groundwork for taking advantage of further improvement opportunities.

To answer the second part of the research question, eight improvement suggestions are provided to aid the improvement of construction PP&C practices by emphasizing and advancing decentralized (suggestions 1–6) while also recognizing the partial necessity of centralized (suggestions 7–8) decision-making. The suggestions are as follows (adapted from Publication 2):

1. “Recognizing production teams’ tacit responsibilities and internal dynamics and embedding them in formal PP&C processes;
2. Ensuring the earlier and more intense involvement of crew leaders and first-line workers in planning, officially determining their responsibilities in decision-making, and allocating more time and resources for their micro-level PP&C;
3. Providing training for role-based PP&C, for crew leaders and workers, but also for managers to act as facilitators;
4. Providing support for increasing trust with team-building and face-to-face communication and supporting adequate information transparency;
5. Ensuring ownership of decisions and a sense of autonomy for production crews;
6. Developing cultural change toward the recognition of the benefits of decentralization;
7. Ensuring project-level alignment with central coordination; and
8. Ensuring overall risk management with central risk assessment and coordination.”
Supporting RQ3: How to improve construction PP&C practices and production flow by combining takt production and decentralized decision-making?

In addition to examining takt production and decentralized decision-making individually, the third central contribution is providing understanding of their combined effect. Particularly, through formulating, implementing, and validating a decentralized takt production framework, insights into how takt production and decentralized decision-making jointly contribute to PP&C practices and production flow are provided. Our study results indicate that decentralized decision-making has the potential to improve PP&C practices and complement the shortcomings of takt production (also, e.g., Frandson et al. 2014), for example, by having positive effects on operations flow in low-maturity implementation, available immediately. The results of the current dissertation and from the literature (e.g., Frandson et al. 2015) indicate that implementing decentralization drivers particularly supports flow-efficient takt production.

The novelty of the present study and formulated model came from the approach to involve first-line workers in the decentralized takt production process, which has not been done in the previously documented implementation initiatives. Indeed, this approach seems to support achieving the pursued benefits, such as improved process and operations flow and an effective PP&C process. The joint effects of decentralized decision-making and takt production and the suggestions for improvement mostly align with the findings regarding the individual implementation of takt production and decentralized decision-making. However, the implementation did not fully reach the first-line workers through the entire control phase, which forms a limitation in generalizing the results and assessing the model’s utility. The model was constructed based on previous takt production and decentralized decision-making literature; however, the model was detailed based on the requirements of the case at hand. Thus, the model can serve as a basis for further decentralized takt production implementations given that the specific requirements of each implementation situation are also considered individually.

Successfully implementing takt production and decentralized decision-making seems to require an extended effort when done individually, and our research suggests this is also the case when they are implemented jointly. Successful implementation, especially in the control phase, seems to require increased attention on the involvement and training that exceeds individual projects and organizations. Based on these observations, our research resulted in providing improvement suggestions for the framework and further implementation of decentralized takt production, primarily concerning training participants and developing their understanding of implementing novel PP&C approaches. Obtained from the third publication (p. 13), the suggestions are as follows:

1. “More systematic and cross-organizational involvement and training of decentralization principles should be ensured to empower site teams to act as autonomous decision-makers and managers to serve as facilitators;
2. More extensive training and implementation of takt production practices should be ensured for project participants, focusing on effective ramp-up and daily production control in which site teams (including workers) can actively participate; and

3. The role of logistics management should be improved, for example, by involving material suppliers and logistics operators in the decentralized PP&C processes.”

In terms of the synergy between takt production and decentralized decision-making, our results suggest that their combination can simultaneously improve both flow and PP&C practices by, for example, achieving a more proactive touch to production management and increasing worker well-being. While takt production provides a structure to systematically plan, control, and improve the production system, decentralized decision-making induces the drivers and advantages that improve the PP&C overall performance and are, in turn, needed to manage takt production effectively. The central management of takt production does not seem compelling because of missing opportunities that decentralized decision-making can seize. Although these novel approaches can flourish independently, it would seem beneficial to implement them together.

Although certain benefits (such as improved overall flow) can be achieved even with low-maturity implementation, it might require that decentralized practices are deliberately implemented only for certain parts of the process. For example, in the third publication, forming the high-level takt plan with centralized decision-making was seen as adequate when the teams’ maturity with takt production was low because it advocated for better project-level coordination and overall risk management (also Lanaj et al. 2013). Nevertheless, when decentralized decision-making is holistically implemented, the results indicate a further increased magnitude of the intended positive effects of decentralization and takt production in a situation of combined implementation.

Our findings highlight that considering and effectively integrating the supply chain and supporting flows (e.g., design and material flows; Sacks 2016) seems to be a necessary enabler for successful takt production, whether decentralized decision-making is present or not. Effective integration could provide vast opportunities for improvement, supporting value creation and even distribution of the implementation benefits, with both takt production and decentralized decision-making. For effective integration, adequate delivery models and contractual structures should be considered, which can be further supported by the decentralization drivers, such as the adequate training of project participants through the whole supply chain, including adequate collaboration between contractors and the client.

**Main RQ: How takt production and decentralized decision-making contribute to construction production planning & control practices and production flow?**

The current research contributes to existing knowledge on takt production and decentralized decision-making in construction production planning & control.
As synthesized in Figure 6, the findings underline that **takt production** positively contributes to flow, especially aiding good process flow. To fully achieve the intended benefits (and mitigate the adverse effects in the long run, such as increased managerial efforts), certain drivers need to be deployed that consider efforts in takt planning, takt control, continuous improvement, and supply chain integration. **Decentralized decision-making** positively contributes to project performance by improving worker well-being and performance, while the employment of decentralization drivers and alignment with centralized decision-making is needed to mitigate the negative effects on overall risk management and the coordination of teams. **Decentralized takt production** aids in achieving good flow holistically, particularly through its positive effect on operations flow, and further magnifies the individual positive effects of takt production and decentralized decision-making. Notably, the presented adverse effects seem to diminish as the implementation maturity increases with both takt production and decentralized decision-making.

**Figure 6.** Synthesis of the dissertation findings.

Although the presented benefits can be connected to the implementation of takt production, decentralized decision-making, or their combination, it should be noted that explicitly measuring the sole effects of individual novel PP&C practices can be difficult due to the unique nature of construction projects, and as such novel methods rather complement than compete with each other. Thus, instead of exploring which method would provide best results individually, in this thesis the viewpoint has rather been to explore how such novel approaches could best operate in collaboration and what drivers they need to succeed. However, exploring such differences can be seen as a possibility for future research.
5.2 Practical contribution

The (construction) management research has recently been under critical discussion concerning its relevance, its meaningful influence on practice, and its role in addressing business problems (e.g., Ivory 2017, Koskela 2017, Lavikka 2020, Scala et al. 2022). Inspired by this discussion, this dissertation aimed—in addition to providing sound theoretical contribution—to address practical business problems such as the struggle to complete projects faster that simultaneously increase in complexity (e.g., Dave et al. 2008) by considering the possibilities of the selected, novel PP&C approaches.

This dissertation provides knowledge for industry professionals on how to systematically and predictably use takt production and decentralized decision-making to improve PP&C practices and production flow (and furthermore, effectiveness) while answering the needs of modern construction project production. Notably, the provided improvement suggestions can be implemented (and their benefits reaped) in varying time horizons—now or in the near future (e.g., providing training and ensuring production crew involvement in the PP&C process) or through longer-term efforts (e.g., advancing a management culture that naturally aligns with decentralized decision-making structures). More specifically, the practical contribution can be divided into two levels: projects and businesses.

First, on the project level, the dissertation provides a practical understanding regarding the effects of PP&C approaches for projects and individuals, along with how to most effectively reap the benefits. In addition, knowledge is provided on supporting the understanding of how takt production implementation affects production flow and how decentralized PP&C affects managers and production crews. The research also provides an understanding of the effect of the actions of managers and production crews (including first-line workers) on the success of PP&C practices. The results indicate that, if adequately developed and executed, effective production planning, control, continuous improvement, and supply chain integration can provide vast opportunities for improved performance and flow for projects.

Second, on the business level, the dissertation provides a practical understanding regarding business unit development (e.g., the possibilities that increasing takt production implementation maturity through continuous improvement over projects can yield), operations strategy development (e.g., the synergy of takt production, decentralized PP&C, and innovations such as industrialized construction), and cultural change (e.g., the possibilities of decentralized decision-making in terms of worker well-being). To successfully achieve such improvements, the results suggest paying increased attention to deeper supply chain integration and further development of the delivery methods and contractual models to align with the specific needs of the implemented novel PP&C approaches.

Although understanding the possibilities and driving the implementation of takt production and decentralized decision-making can yield some immediate positive results, reaping all the benefits seems to require an extended effort and partial change in managerial attitudes. Particularly related to decentralization,
a holistic implementation would need a thorough involvement of first-line workers in decision-making to bridge the epistemological gap and tackle the related problems. This would require better recognition of the internal dynamics of production crews (also Chinowsky et al. 2008), more intense involvement of first-line workers in the PP&C process, role-based training (also for managers to act as facilitators) and extended resources to cope with partially increased planning & control responsibilities.

5.3 Limitations and future research avenues

For the final part of the discussion, the most prevalent limitations and future research avenues are presented, which have been compiled from the suggestions from the individual publications and are complemented by insights generated by the above discussion.

First, the case study approach and case selection possess limitations for the generalization of the results. Because the empirical results are limited to a certain number of cases and primarily to the Finnish construction sector (except for the four case studies conducted in other locations in the first publication), in the future, it would be desirable to broaden the inspection of decentralized PP&C practices, decentralized takt production, and first-line workers’ viewpoints to other geographical locations to allow for better generalization of the results. Moreover, investigation of takt production from the viewpoint of the whole production (in addition to the interior phase, being the focus of the empirical studies) could support a more holistic understanding. A broader spectrum of case studies could also allow for a wider comparison between different takt production approaches, centralized and decentralized PP&C, and other (novel) PP&C approaches. Furthermore, as the validation of the decentralized takt production framework was limited only to a single case study, a wider validation regarding utility and applicability of the framework could be conducted in future research. In addition to limiting the analysis to the production of individual projects, future case studies could also consider (longitudinal) project portfolio and business-level cases.

Second, the individual studies have indicated a need for further quantitative research with rigorous data-based analysis, perhaps through the lenses of positivism. Given the challenges of multi-method studies with competing paradigms, these studies could nevertheless have attractive opportunities to support the obtained exploratory findings (Dainty 2008), yielding a more holistic understanding of the phenomenon and providing opportunities for increased generalizability (Flyvbjerg 2006). Such quantitative research could also provide more accurate results on the found positive and adverse effects. The possible avenues for quantitative research are 1) assessing the quantities of flow (e.g., through the lenses of the created theoretical model and by using measurements with equipment such as video cameras or worker movement tracking), 2) analyzing the economic effects and the effects on production teams’ performance and well-being, 3) a more rigorous assessment of the effects on project perfor-
mance (e.g., quality, safety, value creation, waste reduction, and schedule performance), and 4) analyzing the effects related to PP&C decisions (e.g., takt area shapes and sizes, takt times, takt wagon distribution, and buffer use).

Moreover, quantitative research could also be employed through simulations (e.g., agent-based simulation; Watkins et al. 2009) that could aid the practical development of the PP&C approaches but also advance new lines of development, such as automated data collection and analysis and development of digital twins (Sacks et al. 2020). Automated and algorithm-based data collection, analysis, and representation could also yield practical benefits for takt production and decentralized decision-making, lowering the need for managerial resources and providing increased opportunities for continuous improvement (e.g., Jabbari et al. 2020, Zhao et al. 2020). In terms of decentralized decision-making, the implementation of such tools could provide improvements in collecting and sharing information while supporting transparency and autonomous decision-making.

Third, it should be noted that inspecting construction production flow only through streams of process and operations flow is a simplification and only concerns flows directly related to site activities. Other flows, such as design information, process information, communication, project portfolio, material, and equipment, can also be distinguished (e.g., Garcia-Lopez 2017, Koskela 2000, Sacks 2016). Also, one should be aware that process and operations flow might not always behave exactly, as illustrated in Figure 1 because of the complexity of projects. For example, if the produced products are not identical or the activities needed to conduct them are not similar (e.g., apartments might have a vastly different sequence of activities than staircases) or if a single production crew is responsible for producing several different activities, their movement through the locations might be far from linear. However, given these constraints, the selected conceptualization offers a tangible way to inspect the quality of production flow while providing insights for improvement (Sacks et al. 2017). In addition, basing an analysis on a well-acknowledged conceptualization from manufacturing (Shingo and Dillon 1989) and construction (Sacks 2016) offers solid grounds for inspecting production flow in a detailed manner in the context of the present dissertation. More detailed inspection, simulation, and measurement of the combination of additional flows are suggested avenues for future research.

Finally, several future research suggestions related specifically to takt production or decentralized decision-making were identified. Regarding takt production, these include investigating the role and impact of the delivery methods, and the implementation effects on the whole production supply chain in addition to the effect on individual organizations or projects. Regarding decentralized decision-making, future research suggestions include investigating how longitudinally implemented decentralized decision-making structures would drive cultural change, and how digitalization could support decentralization by, for example, facilitating more efficient dissemination of information. Moreover, exploration the effects of different decentralization implementation mechanisms, such as various degrees of decentralization or forms of decision-making.
power structures could be studied in the future. Comparing the identified improvement avenues of both approaches to the previous development of similar fields (such as manufacturing and other project-based industries such as marine shipbuilding) could also offer valuable insights into how the construction PP&C practices could be improved in the (near) future.
6. References


References


References


The construction industry has come under growing pressure to build increasingly complex projects and to do so more efficiently. This dissertation explored how novel approaches—takt production and decentralized decision-making—could improve production planning & control practices while increasing production flow.

The first contribution of the dissertation is providing an understanding of the effects that different takt production domains and distinct drivers have on production flow and how they support takt production implementation.

The second contribution is providing an understanding of how a better balance of centralized and decentralized decision-making could support an improvement of construction PP&C practices.

In addition to examining takt production and decentralized decision-making individually, the third contribution is providing an understanding of their combined effect through formulating, implementing, and validating a decentralized takt production framework.