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ACHIEVING A 4-HOUR TAKT TIME – AND DRIVING CHANGE WITH IT

Jaakko Riekki[1], Jukka Rannisto[2], Joonas Lehtovaara[3], Olli Seppänen[4], and Antti Peltokorpi[5]

ABSTRACT

This study seeks to validate the hypothesis that takt production can be used as a driver for implementing several lean construction concepts together and for making them work as a system. This is done by studying a single case project where takt production with a 4-hour takt time was a core element of the operating system. In studying the case, a set of lean construction concepts found present in the project are extracted and analysed. It is concluded that takt production and in particular the short takt time worked to integrate the stakeholders and enabled the individual lean construction concepts to work in a tight relationship. Future case studies could be more explicitly designed to further validate the hypothesis.

KEYWORDS

takt production, daily management, logistics, continuous improvement, collaboration

INTRODUCTION

According to Koskela et al. (2002) in their description of a Lean Project Delivery System (LPDS) there are two differing interpretations of lean construction: (1) application of lean production methods to construction and (2) a new theory-based methodology for construction that draws inspiration from lean production. In practice the approach of the first interpretation has demonstrated good results yet advancing towards the second would be desirable.

As methodologies akin to the second interpretation, we have The Last Planner System (LPS) (Ballard & Tommelein 2021) that is an important component of lean construction and has gained wide acceptance, and the Location-Based Management System (LBMS) (Kenley & Seppänen 2009) that attempted to bring construction planning together with design scheduling, procurement planning and production control. These systems however have not yet been able to bring to practice the transition from lean construction as a kit of methods to a holistic theory-based system. On the other hand, applications of lean production methods have demonstrated performance gains in individual case projects but there seems to be a knowledge threshold at the point where we are looking for ground up methods that can be used as the underlying drivers from a set of separated elements towards a system of interrelated concepts. By ground up we mean that it can be applied in practice even in the absence of a theory-based methodology.

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Takt production has been suggested as one such underlying driver. Lehtovaara et al. (2020) developed a maturity level model that describes how the development of an organization's takt production capability can be used to connect and implement many other lean construction concepts. Peltokorpi et al. (2021) identified takt production as one key driver for systemic change and suggested a conceptual framework of integrating a set of sub-systems present in construction, that need to be developed together in order to achieve sustainable development. From a more single project-based viewpoint Tommelein & Emdanat (2022) described takt planning as an enabler for bringing together and as a starting point for continuous improvement using lean principles. Studies involving takt production have also highlighted the need to connect with other lean production concepts. For example, Lehtovaara et al. (2021) presented how takt production contributes to construction production flow but with the requirement of significantly increased effort in terms of planning, control and continuous improvement.

Building on this idea we suggest that one way of gaining more knowledge about how to make progress in the transition from applying a set of tools towards applying a management system is to study a successful takt production case project where a scattered set of other lean construction concepts were identified, analyse the effects of the individual efforts, look at how they worked together and, specifically, how they related to the takt. By doing this we can seek to validate or refute the hypothesis that takt production can function as a ground up driver towards a more holistic approach for future lean construction implementation. To this end, this study aims to explore a case project where a short takt time of four hours is highlighted as a novel concept for driving production flow and where many other lean construction concepts were found to be present.

Among these concepts are collaboration, as argued useful by Koskela (2022), integration of design and procurement, an interesting avenue for furthering collaboration as explored for example by Uusitalo et al. (2019), and the core lean principle of continuous improvement. Top management support is required because an implementation of lean tools and methods by themselves often leads to failure without a cultural change in the organization (Walter et al. 2020). Similarly, Hackler et al. (2019) shares efforts towards developing lean leadership and disseminating lean through a larger scale training program. These views are supported by a questionnaire sent out to LCI members that propose barriers for lean implementation (Demirkesen et al. 2019). Emphasis on planning effort is another common lean production idea and has been demonstrated as a rewarding experience for example by Ghio et al. (1997).

Binninger et al. (2018a) showed the power of small batch-sizes, which came together with intensive daily management and the idea of andon pulls i.e., to stop to fix problems as they arise. Also, relating specifically to takt production, several control adjustment mechanisms have been compiled (Binninger et al. 2017) and the daily management activities of construction managers have been analysed (Binninger et al. 2018b).

Tetik et al. (2019) describe industrialized logistics to better serve the needs of construction. Visual management has as well been experimented with on construction sites with promising results for example by Grönvall et al. (2021). First-run studies (Ballard & Tommelein 2021) may also be considered. Digitalization (Sacks et al. 2020) is a tool that opens possibilities for implementing many of the other lean concepts.

In the next section, the method of analysis of this study is described, including a brief summary of the project general information. After that, the findings of the analysis are presented, and finally, implications of the study are discussed.

METHOD

In the following, we first explain the method of this study and then give a brief general description of the case project and how it was managed.

STUDY METHOD

Because we examine a single interesting project noticed by the authors, the method used is a single case study. We gathered data from the project by gaining access to the project databases and conducting interviews. We then searched the data to extract a set of lean construction concepts evident in the project. After that we analyzed how the concepts worked in the project and finally, we report on the findings of the analysis.

The data used in the study consisted of

documents such as schedules, production plans, process descriptions, contracts, project presentations, photographs and design documents,

digital data platforms that were used for process planning (Miro), quality control and issue tracking (Congrid) and material management (NPL),

4d video animations that were created to visualize the takt phase,

unstructured interviews with the project participants who were involved in planning, managing and leading the project and

site observations by the first two authors that consisted of general site walks, site personnel interviews on the spot and included observation of the daily huddles.

The extraction of the concepts to be analysed was achieved through discussions between the authors that followed a preparation made by the first author's study of the data. It was noted that the set of concepts could be grouped and renamed in many ways, but the aim was to settle on a set that is representative of what was learned from the data, does not have excessive overlap between the concepts and would look familiar to most lean construction professionals.

An analysis on how the concepts were used, what, if any, were their benefits or drawbacks and what could be concluded from the experience of implementing them was carried out by asking the following questions for each of the identified concepts:

(Q1) How were the lean and takt concepts present in the case project?

(Q2) What were the apparent benefits or drawbacks in implementing the concepts?

(Q3) What can be concluded from the experience of having implemented the concept?

The answers to these questions and their data sources are presented in the findings section. A deeper reflection on the analysis and the research hypothesis is presented in the discussion section.

CASE PROJECT DESCRIPTION

The case was a renovation project where an office building was turned into a hotel. The site's location was a crowded city center with limited space, posing a challenge for logistics. The building was constructed in several phases from 1920 to 1952 and had since been transformed through other renovation and new construction projects. Through these transformations the building has a varied history of use from industrial to office before being turned into a hotel.

The project consisted of around 29 000 gross m^2 which included 352 hotel rooms with their corridors and other hotel facilities such as restaurants, spas, reception areas and technical spaces. The project started in January 2020 with the demolition phase and was finished and handed over to the client in June 2022.

The construction of the hotel rooms and corridors starting from interior walls were managed by takt production while the other construction phases were managed by a combination of LBMS flowlines and a modification of the Last Planner System. We will call the phase of production where takt production was used the *takt phase* which is also the focus of this study. Separated from the takt phase, a preparation phase of demolition, structural changes, concrete casting and floor levelling was managed by the other means before the takt phase started. The

takt phase started in January 2021 and was finished in April 2022, with total duration of about 16 months.

The project was managed by a project management organization (PMO) who was involved early in the project by the client from goal setting to design process management, procurement preparation and finally to being responsible for the construction site management. In the construction phase the PMO was responsible for the planning and coordination of operations including design, the trade partners and the logistics. However, the designers, trade partners and the logistics contractor were in direct contractual relationship with the project client as part contractors and not with the PMO, who acted only as a project management consultant and a supervisor. By the PMO's requirement, the part contracts of the trade partners were included with a takt appendix that described the takt principles to be used in the takt phase and required the trade partners to take part in takt planning, daily huddles during the takt phase, preparation of work in the takt plan and quality assurance of the finished takt areas.

In the project management role, the PMO took strong leadership in planning, facilitating collaboration and implementing several lean construction concepts in the project. Specifically, the enforcement of takt production was due to the PMO's leadership.

The project was described as successful by the PMO and the client from the schedule point of view. The PMO also reported that in their view specifically the use of takt production in this project eliminated several sources of waste compared to both the other phases of the same project and other similar projects without takt production.

FINDINGS

Figure 1 depicts the set of lean construction concepts that were found present in the case project arranged into four groups. The concepts to be analysed by answering the three questions are in the white boxes.

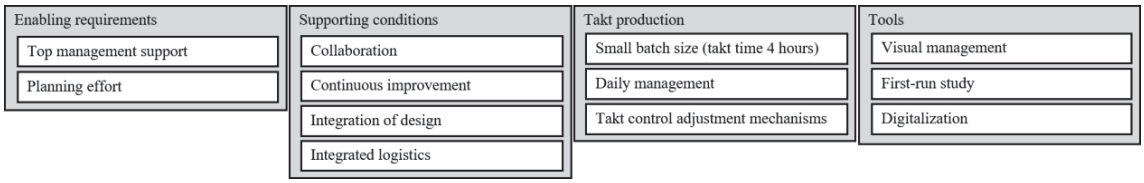

Figure 1: Lean construction concepts found in the case project arranged into groups.

Top management support: The site visits and interviews indicate that the top management of the PMO at the site put a lot of pressure on the management team, the logistics operator and the trade partners to make efforts in new ways of working along the lines of lean construction concepts. The highest-ranking manager at the site had knowledge and experience about lean construction concepts and made efforts to put them into practice through frequent coaching of the management team. In addition to putting pressure, the top management expressed an explicit recognition of the need to allocate an uncommonly high number of resources to the planning phase in order to enable a thorough preparation. (Q1)

These observations make clear the benefit that most of the lean efforts would not have been realized without the pressure and commitment from the top management. There was however no formal lean leadership initiative present, and some members of the management team were observed in a few situations as having been somewhat at a loss in the middle of several new methods pushed by the leadership all at once. (Q2) This was taken to be evidence for the proposition that, in addition to support from top management, getting a good grasp of lean construction concepts requires proper training and coaching. (Q3)

Planning effort: As hinted above, the planning documents and interviews indicate that an exceptional effort was put in planning the takt phase from early on. Evidence of this was also an initial two-day workshop with a large group of the PMO company's production management

staff, that began identifying the work steps in the production process along with their quantities and performance rates. This workshop was held around six months before starting production, was led by an external consultant and acted simultaneously as a training session for the participants into takt production principles. In the workshop the knowledge base of around 15 experienced construction professionals was leveraged to gain insights into the details of the production process. Afterwards a group of 2-4 people was assigned to develop the plan further. Around three months prior to the start of the takt phase, two core members of the group worked full-time in fine-tuning the plan. Similarly, around six months before production start, the logistics contractor was tasked with defining the supporting material management processes required by the takt plan. The materials required by the takt work packages were quantified in detail and the methods of transportation as well as lay-down areas on site was planned for each type of material. Closer to production, a preparation meeting was held with each trade partner where a short training of takt principles was given and their input into the takt plan's details and feasibility was solicited. (Q1)

According to the interviews the production management team along with the logistics contractor gained benefits from the planning effort by being well versed in the plan ahead of production which gave them confidence in controlling the takt phase and dealing with the trade partners. Good understanding of the required material and worker resources enabled the production management to tackle surfaced problems quickly by being able to refer to the already gained knowledge. In short, the interviews indicate the sentiment of the management team that putting this exceptional effort in planning and preparation helped in creating and controlling a good production process. (Q2)

It is difficult to discern the economic impact of the decision on the amount of planning and preparation. The case project can however be taken as anecdotal evidence for the hypothesis that the line after which more effort on planning does not gain a net benefit anymore has not yet been reached. It should also be noted that the management team of the takt phase had no prior experience or knowledge of takt production. The careful preparation was used simultaneously as a training opportunity. (Q3)

Small batch size (takt time 4 hours): From the schedules and planning documents it can be seen that the takt plan was built around the smallest space unit of one hotel room and a corresponding length of corridors as the takt areas, which eventually led to decision on using a takt time of four hours i.e., a half workday. This is illustrated in an excerpt of the takt plan and progress record in Figure 2. The interviews reveal that the target for a short takt time was set early in the planning phase explicitly because of the perceived benefits of a small batch size. During the planning process the target was deemed feasible and incorporated into the plan. (Q1)

As told in the interviews, the short takt time enabled a lot of flexibility in the work step definition, sequencing, buffer management as well as levelled the material flow and drove the tight control efforts during production. As evidenced by the schedules, planning documents and progress records, planning and controlling with a short takt time also made the required work steps and progress tracking highly visible and accurate. The feasibility of controlling such a short takt time was said in the interviews to have been initially questioned due to the perceived increased management burden. However, the short takt time was later not only proven feasible but indeed regarded as the key driver for success. (Q2)

Through interviews it was clear that the management team felt that the burden increased by the short takt time was set off and well paid back by the tightness, flexibility and accuracy of control. These observations are similar to what Binninger et al. (2018b) described in their experiment with a short takt time on a smaller scale project. (Q3)

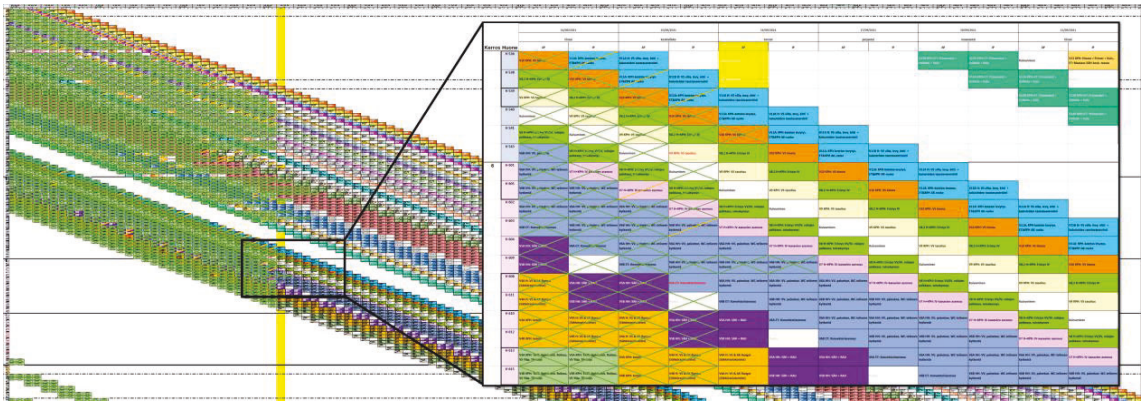

Figure 2: An excerpt of the takt plan and progress record on 16th September 2021 illustrates the plan with a 4-hour takt time. The progress was recorded for every takt in the daily huddles. A green double cross over a wagon stands for done, yellow single cross stands for started but incomplete.

Daily management: The PMO enforced a disciplined daily management process of takt control through worker huddles where all the trade partners were required to be represented every day. In the huddles, observed by the first two authors, the progress in the preceding two takts reported by the trade partners were recorded in a schedule printed out on a large sheet of paper for the purpose of visualization. The progress was simultaneously also recorded in the digital spreadsheet schedule. Figure 3 shows what the daily huddles looked like. Any issues raised during the huddle were also digitally recorded on a separate spreadsheet where in total over 7,000 issues were found having been recorded during the takt phase. Immediately after the huddles, the management team went to solve the surfaced issues with the trade partners. (Q1)

Figure 3: The progress was recorded both digitally and on a visual board in the daily huddles. The raised issues were also recorded in a digital spreadsheet.

The daily huddles served in sharing a common situational awareness of the takt process and enabled the trade partners to get a fast response to issues in their work. At the same time, the progress of planned work was updated and visualized daily. (Q2)

Learned from the interviews, the daily huddles required some enforcement from the PMO. The site observations confirm that some trade partners were reluctant to take part in the huddles, since the huddles took around 30-45 minutes of their workers' time. The PMO held the discipline by referring to the contractual clauses about the huddles. After initial backlash, the

huddles became routine and were attended to by almost all trade partners even when they were longer than required in the contract, because they found them useful. After the project was finished, the PMO identified the need to consider breaking the daily huddles apart into several smaller size huddles in order to shorten them in their future projects. (Q3)

Takt control adjustment mechanisms: The studied schedules and interviews reveal that at least the following takt control adjustment mechanisms similar to presented by Binninger et al. (2017) were used during the takt production phase: contents of work steps were modified, the sequence of wagons was changed, new work steps were added, buffer wagons were added and takt areas were omitted in order to protect the train flow. In addition to these the worker resources and material delivery quantities were adjusted as knowledge about their requirements was gained during production. Notably there was one situation where a decision was made to split and stop the trailing part of the train in order to solve problems that had accumulated delays and blockages. The trailing portion of the takt train behind the delayed wagon was stopped for 2 weeks to let the delayed wagon catch up and solve the problem. The leading portion of the train was not affected by the stoppage, and it was kept moving normally. The stoppage time was sufficient for the catchup and the train was restarted with the modifications caused by the stoppage. According to the PMO the decision of stoppage for a specific amount of time was clearly communicated to the affected trade partners, and no major complaints arose. The schedule had enough planned buffer at the end to compensate for the delay caused by the stoppage. (Q1)

Problems that were surfaced during production caused some delays, but the deviations were able to be adjusted for with the major benefit that the plan was kept under control throughout the takt phase. One notable downside to the frequent use of adjustment mechanisms was the effort required to update the modified schedule. The takt plan was drawn on a spreadsheet with a low level of automation and each change took several hours or in some cases even a whole day of work to update and repost on the site. (Q2)

Interviews confirm that the adjustment mechanisms were essential in keeping the takt train flowing. The short takt time along with the upfront effort spent in planning made the takt plan very flexible for adjustments even if they required some effort in replanning. The problem of increased effort required for manual data management can presumably be mitigated by development and adoption of more sophisticated digital tools with a higher level of automation for creating takt schedules. (Q3)

Collaboration: The PMO launched a system of workshops aimed at facilitating collaboration between the site management team, the logistics operator and the trade partners. As described in the interviews, the system was called “three-based-meetings” referring to the usual three stakeholders of the PMO, a trade partner and the logistics operator who all had a stake in most matters relating to the takt phase. In contrast to a prior standard way of sending documents back and forth, the PMO organized workshops together with the other stakeholders where planning and continuous improvement efforts were carried out in collaboration. (Q1)

The top site manager of the PMO described and the management team confirmed an anecdotal example where the planning of materials for a trade partner’s work package took several weeks when they first tried it in the documents transfer way and was condensed to a single 1-hour workshop after the launch of the system. (Q2) It was also noted that merely the definition of a process for the purpose of collaboration helped in achieving a collaborative way of working. A high impact was achieved with a small nudge. (Q3)

Integrated logistics: According to the PMO, material flow management was identified early as a key requirement for success in the takt phase because of the small takt areas and the challenges posed by the site’s location at a city centre. Study of the planning documents showed that the material quantities were calculated, and a delivery strategy was planned for each work package individually.

The logistics operator used a material management software system to manage all the material flows. The takt schedule was imported to the software, where the bills of materials required by each takt wagon were also added. By doing this an appropriate material package was linked to every work package of the takt plan. The material management process was presented, and the corresponding software was demonstrated by the logistics contractor to the first author.

As per a process map created by the logistics operator, the materials were delivered depending on their type through one of two types of flow: (1) The large and heavy materials such as gypsum boards and bricks were delivered using an off-site warehouse as a buffer to level the flow. The material management system produced a plan for daily picking and delivery from the off-site warehouse to the site and eventually to the corresponding takt area on a just-in-time basis one takt time ahead of the work package. (2) For smaller materials such as water faucets and light switches, an on-site area was provided for the trade partners to be used as a supermarket-like buffer. These materials were delivered directly to the site supermarket and picked by the trade partners as required by the takt schedule. The supermarket area was also used as a one-day buffer against expected delivery failures. (Q1)

Through site observations and interviews it was verified that the material buffers on site were able to be kept small which helped avoid congestions and unnecessary moving. The average material buffer was estimated to have been on average no more than one day's worth for most of the logistically important material types. The site management also felt that the daily delivery plans simplified the daily management of the logistics even if they were not meticulously followed and controlled. (Q2)

Even with such lean material buffers a lack of materials due to supply disruptions was reported as not having been a major problem for the flow of work, which leads to the conclusion that the material management process was reliable enough to enable them. (Q3)

Continuous improvement: The interviews indicated that occasionally during the project, out-of-standard conditions compared to the planned work processes were spotted and meetings to manage the specific issues were held (Q1) and due to the held meetings, several sources of waste were reduced during the project. (Q2) This is in alignment with the general expectation that explicitly defined work processes enable continuous improvement efforts to tackle issues in a formal way. (Q3)

Visual management: As observed during the site visits, the takt plans were printed out on large sheets of paper and put on display in the daily huddle area. Smaller versions of the same sheets were posted on site in common walking areas such as staircases. 4D animations of the takt process and operations flow were created and kept running on displays in the daily huddle area. The hotel room numbers were painted on the floor in the corridors in front of the room entrances. (Q1)

According to the PMO, the workers were frequently found around the posted takt plans either discussing their issues with each other or reminding themselves of which area they were supposed to work in and go to next. Taking note of the room numbers in the takt plan, the painted room numbers made it easy for them to be sure about the correct work location. The 4D animation of the operations flow made the takt train highly visible which presumably helped in gaining common understanding about the direction of the flow. The process flow 4D animation was suspected to be mostly helpful in gaining initial understanding about the sequence of work for newcomers to the project (Q2)

The painted room numbers were unanimously considered as very helpful for orientation at the site and as they were easy to create, the idea was found to be a true low hanging fruit. The 4D animations seemed helpful at the start but updating them to take into account every takt control adjustment was considered too burdensome to do. (Q3)

Integration of design: (Q1) There was a defined documented process for escalating design problems surfaced during production according to the size of the problem and the level of involvement required. A presentation witnessed also by the first author was given to the designers to inform them about the takt process and the urgency of solving problems as they appear. In addition, an interview revealed that in order to make the urgency feel more real, the designers were invited to visit the site shortly after the beginning of the takt phase intentionally to let them see for themselves the hectic nature of the production flow. After this a response time of one takt was sought in order to tackle the problems that can be solved quickly.

The interviews with the management team of the takt phase confirmed that the designers were better prepared to being on call during the takt phase due to at least in part the involvement initiative. Involving the designers personally with the takt phase helped to create clear lines of communication between the site and the designers, and the sense of urgency to solve problems reached the design team. (Q2)

According to the site management, the explicitly defined escalation process was not strictly enforced. This was mostly because solving most issues was too straightforward to warrant any need for a formal process. (Q3)

First-run study: According to interviews and witnessed during a site visit, a mock-up of one typical hotel room was planned and built off-site in order to gain knowledge about the potential problems in the details of the work steps. (Q1) However, because the mock-up was not completely finished before the start of the takt phase its usefulness was limited to the planning phase. (Q2) In order to gain benefits from a first-run study, the process needs to be planned and managed adequately in advance of production. (Q3)

Digitalization: The logistics contractor managed the material flows with a digital materials management system, which was presented to the first author by the logistics contractor. The material management software was also developed for the purposes of the project by the software vendor. Quality control was also managed with a digital cloud platform, to which the first two authors had access. (Q1)

The digital material management system allowed the logistics operator to print out sheets of daily material deliveries for management of picking the materials at the off-site warehouse, packing them into delivery trucks and transporting them to takt areas on site. According to the logistics operator the system reduced manual work in handling the logistics information flows, simplified management and enforced good adherence of the materials flow to the takt plan. The digital quality management system is also generally considered to reduce manual work. (Q2)

The digital footprints of the systems reinforce the view that the materials management system was coupled with a planned workflow that the users were trained in while the quality management system lacked tight coupling with the takt. From this it can be presumed that in order to take full advantage of digital tools, management processes should also be defined and adhered to. (Q3)

DISCUSSION

The decision to use takt production in the project was made early by the project management who had learned about its potential as a lean construction concept. Takt quickly became a dominant theme and emerged as the foundation to link together the treated lean construction concepts in Figure 1. In the planning and preparation phase, takt drove the need for the enabling requirements of top management support and planning effort. The supporting conditions of collaboration, continuous improvement, integration of design and integrated logistics revolved around the takt plan. The takt production concepts of a 4-hour takt-time, daily management and takt control adjustment mechanisms during production were new to most of the management team but worked as an essential part of their operating system. The tools visual management, first-run study and digitalization were all taken in to serve the functioning of the takt phase. All

in all, it seems clear that the decision to use takt production was the key to make the parts come together.

More than that, it was evident that the relationship of the individual concepts with the takt and each other leveraged their benefits. For example, visual management techniques and digital tools facilitated collaboration between trade partners, the logistics operator, designers and the site management team, which happened at the level of daily management, which in turn was enabled by thorough planning at the level of a very small batch-size. The short takt time required a lot of attention to details both in planning and operating, which also worked to bring the stakeholders very close together.

It is therefore suggested that this study of the case project validates the hypothesis that takt production can work as a ground up driver towards implementing a system of interrelated lean production ideas in construction. This does not provide nor negate the desire to search for a new theory-based methodology for construction that draws inspiration from lean production as outlined in the introduction but aims to help in bridging the gap.

As an interesting result from the study, it is wondered whether the enabling requirement of top management support could be argued as the even more important concept than takt production for the success of the project. On the one hand, in the absence of the pressure from the site's top manager, the application of takt production and in consequence all the other concepts would most probably have been less stringent and the benefits highly diluted. On the other hand, takt production was the instrument that enabled applying the pressure.

As limitations of this study, it must be noted that the nature of the data was unstructured and did not fit well for a systematic approach. That being the case, the discussion and conclusions in the findings section represent mostly inferences of the authors through heuristics and experience instead of a rigorous analysis. The study relied heavily as a data source on interviews that are anecdotal and therefore of only limited qualitative value. The findings represent only one case project and are therefore not generalizable.

CONCLUSIONS

Returning to the research question of whether takt production can function as a driver for change from an application of lean production methods in a scattered way to a system where the concepts work together, the case project does indeed suggest that the hypothesis may be valid. As described in the discussion section, all the identified lean production methods related in an important way to the takt and would have lost a lot of their benefits in the absence of the takt. Particularly the short takt time created the sense of urgency needed to force the concepts to come together.

However, even if takt was the engine that made the system run, it needed as its fuel the exceptional involvement of the site management team and a constant input from the leadership in the form of coaching and encouragement. It seemed clear that the takt phase would have gone very differently in the absence of these, which lets us conclude that we should not see takt production as a wonder weapon but rather as a solid foundation for a system.

Future research could further validate this suggestion by designing and running an experiment of improvement effort where takt production is explicitly put at the core and other lean construction concepts are built around it as supporting functions.

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