

THE SYMPHONY OF CONSTRUCTION: A DATA-DRIVEN COMPARISON OF TAKT AND TRADITIONAL CONSTRUCTION

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ABSTRACT

The construction industry has been struggling with inefficiencies and operational flow interruptions in traditional project delivery. In contrast, the Takt planning method is emerging as a lean alternative designed to create a robust and streamlined trade flow. Despite growing takt adoption, the granular effects of takt versus traditional construction of individual worker flow have not been explored. This study conducts a comparative analysis of two case studies, one using traditional methods and one using takt planning. Analysis is based on quantitative indoor positioning system (IPS) data from workers on both projects. The findings reveal notable differences in operational flow. The quantitative data suggests that the traditional environment indicates a "stop-and-work" workflow with high variability and weak coordination between workers. In contrast, the Takt environment shows a stable, rhythmic, and highly synchronized workflow. The indicated contrast in the worker movement patterns suggests the practical differences between the two methods. This paper studies the effects of Takt on individual workers and movement-related waste compared to the traditional approach. The findings suggest that takt production is associated with reduced movement-related waste and more controlled operational flow.

KEYWORDS

Worker tracking, Takt production, construction operations flow, indoor positioning, lean construction.

INTRODUCTION

Traditional construction projects suffer from a 'stop-and-work' pattern for individual workers. This means irregular and fragmented movement, characterised by frequent interruptions and backtracking between work areas. At the system level, this results in high and irregular worker mobility on construction sites that does not add value. This is a key challenge that leads to unexpected delays and reduced labour productivity (Neve et al., 2020). Despite advancements

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in digital technologies, on-site production management often remains rooted in traditional push-based approaches, perpetuating variability and waste (Rios et al., 2015).

The principle of Lean construction pursues a process-oriented approach and seeks to reduce waste between the activities of individuals or teams on the construction site to ensure the continuous flow of value (Ohno, 2019; Womack & Jones, 1996). Understanding the concept of 'flow' is central to Takt Theory, which conceptualises production as the synchronisation of multiple interdependent flows within a defined temporal and spatial structure. In construction, these flows consist of worker, trade, process, material, and operation flows (Tommelein et al., 2022). Prior research has distinguished between process flow, defined as the flow of work through locations, and operations flow, defined as the flow of trades and workers (Sacks, 2016). Existing studies have demonstrated takt production's effectiveness in improving predictability and stability at the project, process, and trade-flow levels (Frandsen et al., 2015; Lehtovaara et al., 2021; Seppänen, 2014).

Prior studies indicate that the impact on trade flows remains inconclusive, as improvements in process flow do not automatically translate into more stable or efficient operational flows at the trade level (Lehtovaara et al., 2021). These studies have largely relied on case-based analyses, schedules, and qualitative observations, focusing on planned production structures rather than empirically capturing how workers actually move and interact on site. In particular, the effects of Takt production on granular operational flow, such as individual worker movement and movement-related waste, remain unexplored.

The integration of two established research streams, Bluetooth Low Energy (BLE)-based worker tracking and studies on the effects of takt production, holds significant potential. Despite the potential, no previous study has investigated the high-resolution digital tracking of individual worker presence and movement across different production systems (traditional vs. takt). This research addresses this gap by analysing worker movement patterns in relation to takt areas, comparing how takt production and traditional construction methods affect the dynamics of MEP (Mechanical, Electrical and Plumbing) labour on site using IPS (Indoor Positioning System) to track MEP workers. Two research questions guide this study:

1. How do worker movement patterns and presence differ between takt and traditional construction sites?
2. What do the worker movement patterns reflect about the production control under takt compared to traditional construction methods?

The study compares the movement patterns through heat maps and quantifies the average daily time spent by the workers on the construction site, along with the frequency of floor changes to quantify the extent of disturbances, which significantly impact the work of MEP workers (Görsch, 2024). The subsequent section of the research study outlines the literature review, research methodology, and case study context. The findings regarding the movement patterns of workers from takt and traditional projects are followed by a discussion of their practical significance and future implications.

RELATED WORK

Research on takt production has primarily focused on optimizing process-location flow and improving coordination on construction sites (Binninger et al., 2017; Lehtovaara et al., 2021). Lehtovaara et al. (2021) findings indicate that takt production can significantly improve process flow by stabilizing work sequences, reducing work-in-progress, and minimizing variability through standardized takt times and capacity buffering. However, the effects on trade flows were contradictory in their model. This is because of the divided management structure of takt production, in which the general contractor controls process flow through time and space buffers. At the same time, trades independently manage their own operational flow through

capacity and plan buffers. This separation makes trade flow inherently harder to stabilize (Lehtovaara et al., 2021).

Tommelein et al. (2022) distinguished between process flow, defined as the flow of the product or location through a sequence of different trades, and operations flow, defined as the flow of agents (trades or crews) through their specific sequence of work steps. While takt production structures the process flow through detailed planning parameters (such as takt time, takt areas, and work sequencing), with some implementations achieving takt times as short as four hours (Riekkilä et al., 2023), trade-level flow depends on execution-level factors, which are difficult to control. These factors include material availability, completion of prerequisite tasks by other trades, crew coordination, and local site conditions (Koskela, 2000; Sacks et al., 2017). However, understanding how operational flow differs under takt compared to traditional methods requires granular data on individual worker movements, which can be obtained by leveraging digital technologies such as Indoor Positioning Systems (IPS).

Previous studies were unable to resolve the ambiguity between process flow and operational flow because they relied on schedules, case-based analyses, and qualitative observations rather than granular, worker-level movement data (Frandsen et al., 2015; Lehtovaara et al., 2021). Recent research has focused on the precise capture and analysis of worker movements to identify opportunities for productivity improvements in construction projects (Murguía et al., 2024; Zhao et al., 2019; Zheng et al., 2021). In particular, Bluetooth Low Energy (BLE)-based positioning systems have emerged as a promising technology to provide high-resolution data on worker presence and movement. However, these studies have not used tracking data to compare worker movement patterns across different production methods, such as takt and traditional construction.

Mohanty et al. (2020) suggested that BLE-based real-time tracking can reveal variability in workers' time spent in assigned work areas, providing insights that can support productivity assessment and workflow improvement. Complementing this, Zhao et al. (2019) showed that BLE tracking can effectively monitor resources in renovation and office projects, confirming the applicability of such systems across different construction contexts. However, BLE-based systems are subject to limitations including signal attenuation in environments with dense building materials, multipath interference, and reduced positioning accuracy in areas with sparse gateway coverage (Zhao et al., 2019). Beyond technical feasibility, worker acceptance is a critical factor for the successful deployment of these technologies. The process of convincing the workers to carry the beacons for productivity improvement purposes, while addressing their concerns about the privacy of personal data, requires a transparent and responsible approach (Murguía et al., 2024).

Leveraging digital positioning systems, it has only become possible in recent years to collect continuous, high-resolution data on individual workers' movements and presence on construction sites (Zhao et al., 2019). Before this, analyses of worker flow and productivity relied predominantly on manual observations, self-reports, or coarse, aggregated production data, which limited temporal resolution, scalability, and objectivity. As demonstrated by Zhao et al. (2019), BLE-based tracking overcomes these limitations by enabling automated, real-time recording of worker presence at specific locations. Thus, combining BLE tracking with takt production analysis enables a deeper, data-driven examination of trade flow and its potential for efficiency improvements that fills the research gap of quantitative approaches (Frandsen et al., 2015; Lehtovaara et al., 2021). This study addresses this gap by using six months of worker presence data from both a traditional construction site and a takt production site to analyse the impact on trade-location flow.

METHODOLOGY

A quantitative approach was adopted for the analysis, based on IPS data collected from two construction sites. The details of data collection and analysis are shown in the Figure 1. The figure explains the steps that were followed to carry out this study. It involves the selection of a system, data collection, data processing, data analysis, and discussion regarding the results. These steps are explained in detail next.

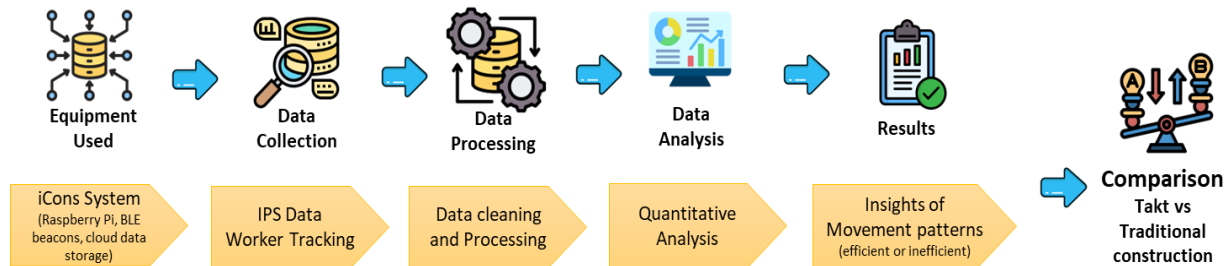


Figure 1: Research Process IPS Data Collection

For the comparison of workers' movement, IPS data was collected from two construction sites that followed two different types of construction methods. A sports arena building (Project 1) was selected that used a traditional construction method, while the other one was a psychiatric hospital (Project 2) that followed the takt construction method. Project 1 had large halls for sports activities with about 30-40% area designed for smaller rooms dedicated to services and support activities. Project 2 was a patient care facility that consisted of a standard corridor and rooms for patients. Unlike a regular hospital, psychiatric hospitals do not require complex medical systems, for example, medical gases and bedhead units. The primary use for the studied area was patient care. The MEP services installed in both projects were similar, i.e., sprinklers, plumbing, electrical, hot and cold water, and HVAC. Thus, the scopes were similar, although layouts differed due to different functions. The sports arena used traditional planning methods, and the hospital used a takt-drive approach with 14 takt areas on each floor and one day takt time.

The number of recorded data points was 5855 for the sprinkler trade in the sports complex and 8062 for the HVAC trade in the hospital; further details are given in Table 1. Different crews were selected for each project because of the challenges of getting informed consent from installers. Each data point represented a time interval during which a beacon was detected by a specific gateway. This setup enabled the quantification of worker presence, movement, and duration of stay across different floors.

Table 1: Description of the cases

Sr. No.	Description	Case study 1	Case study 2
1	Type of Building	Sports Complex	Psychiatric Hospital
2	Location	Helsinki, Finland	Helsinki, Finland
3	Total Gross Area (sqm.)	15000	26000
4	Total Floors	8 floors	6 floors
5	Typical Floor Size (sqm.)	3050 sqm	3200 sqm
6	Number of tracked workers	2 -Sprinkler trade (code: SPR)	3 - HVAC trade (code: HVAC)
7	Type of construction	Traditional	Takt
8	Duration of Data Collection	14th Mar 2024 to 26 Aug 2024	28th Feb 2025 to 6th Aug 2025

An ethical review was conducted before the data collection. Worker privacy was maintained throughout the data collection process. All participants provided informed consent before carrying the BLE beacons, and the collected data was pseudonymized by referring to beacon IDs and trade names to ensure that individual workers could not be identified. No personal information beyond pseudonymized beacon IDs was recorded or stored. The system used for IPS data collection was the iCons system, which has been used for various previous studies related to construction worker tracking (Zhao et al., 2019). The iCons system has three major components. The first one is the Raspberry Pi devices that are placed on the construction site, the second is the Bluetooth beacons that are distributed to the workers, who carry them while moving within the construction site. Each beacon continuously transmits signals that are detected by nearby gateways. These detections are timestamped and logged, generating presence data corresponding to the workers' movements and time spent near specific gateways. The third component is the cloud system that stores the IPS data, which is sent by the Raspberry Pi gateways.

DATA PROCESSING

The pipeline created for IPS data processing is given in **Error! Reference source not found..** Initially, the raw data collected from the iCons system was cleaned and processed to ensure the accuracy and readiness for analysis. First, the CSV files for each worker were loaded in the data cleaning code and checked for the necessary columns and values. Each data point included a beacon ID, gateway ID, and start and end times, which were stored in separate parts (year, month, day, hour, minute, second). Outliers for very short readings (i.e., less than 2 seconds) were removed since these were errors caused by flickering or fluctuations in data signals. Very long periods of single presence (e.g., overnight) were also removed because those could mean that the worker had left the beacon at the workstation. Days with less than 60 minutes of presence were excluded as "absent." Records were merged into timestamps and sorted chronologically.

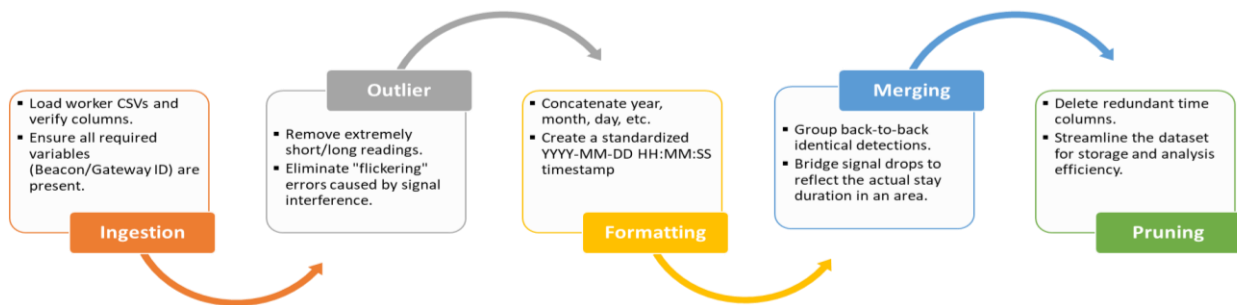


Figure 2: Data Processing Pipeline

After timestamping, the next step was to deal with incorrect detections. All the back-to-back detections from the same beacon at the same gateway were merged into a single continuous record. This helped reduce small gaps caused by signal drops and showed the actual situation of how long a worker stayed in one area. The merged entries kept the earliest start time and latest end time, and a new duration was calculated. Unnecessary time columns were deleted, leaving only key information such as beacon ID, gateway ID, start time, end time, and duration. The cleaned data was then saved in a new CSV file for further analysis.

DATA ANALYSIS

After cleaning, the processed data were analysed to understand how workers moved around the site, how long they stayed in specific work zones, and how their work patterns differed between the traditional and Takt production systems. Each data point in the dataset represented a continuous time during which a worker was detected by a gateway.

The time-based metrics were calculated to quantify worker activity and presence patterns. The time-series nature of the data made it possible to visualize how workers transitioned between the locations over time. Three types of analysis for each set of workers were carried out for each construction method. The types of analysis involved are discussed below.

Frequency of movement between floors: The frequency of daily floor change by the workers was calculated. Each sequential data point indicates the worker's movement from one floor to another. These transitions were interpreted as potential disruptions to task continuity.

Daily presence on the site: The total duration of presence at the site per worker was calculated daily. Presence time extending beyond standard working hours was used as an indicator of overtime. The overtime spent on the site reflects inefficiencies or other factors contributing to delayed task completion.

Floor-wise presence pattern: Heatmaps were developed to show the total daily duration spent on each floor. These visualizations helped in comparing the planned and unplanned movements. The heatmaps also illustrated whether the movements were sequential and coordinated or dispersed and distorted.

RESULTS

The results show a comparison between the movement patterns of the workers in both cases, i.e., traditional construction and takt construction. Visual comparisons of results are shown below.

ANALYSIS OF THE FREQUENCY OF MOVEMENT BETWEEN FLOORS

In the traditional construction project, IPS data from two sprinkler workers were used. Figure 3 shows the floor changes made by each worker per day. The data reveals a high frequency of floor changes. The two sprinkler workers were identified as SPR 153 and SPR 159. Worker SPR 159 was recorded changing floors at an average of 30 times per day, while SPR 153 changed floors around 20 times.

The results for the takt project show much fewer floor changes. Figure 4 shows the number of floor changes per day, organized by worker. There were fewer floor transitions than in the traditional case. The three HVAC workers were identified as HVAC 166, HVAC 170, and HVAC 172. Each HVAC worker changed floors up to a maximum of 20 times per day, i.e., 20, 12, and 16 times, respectively.

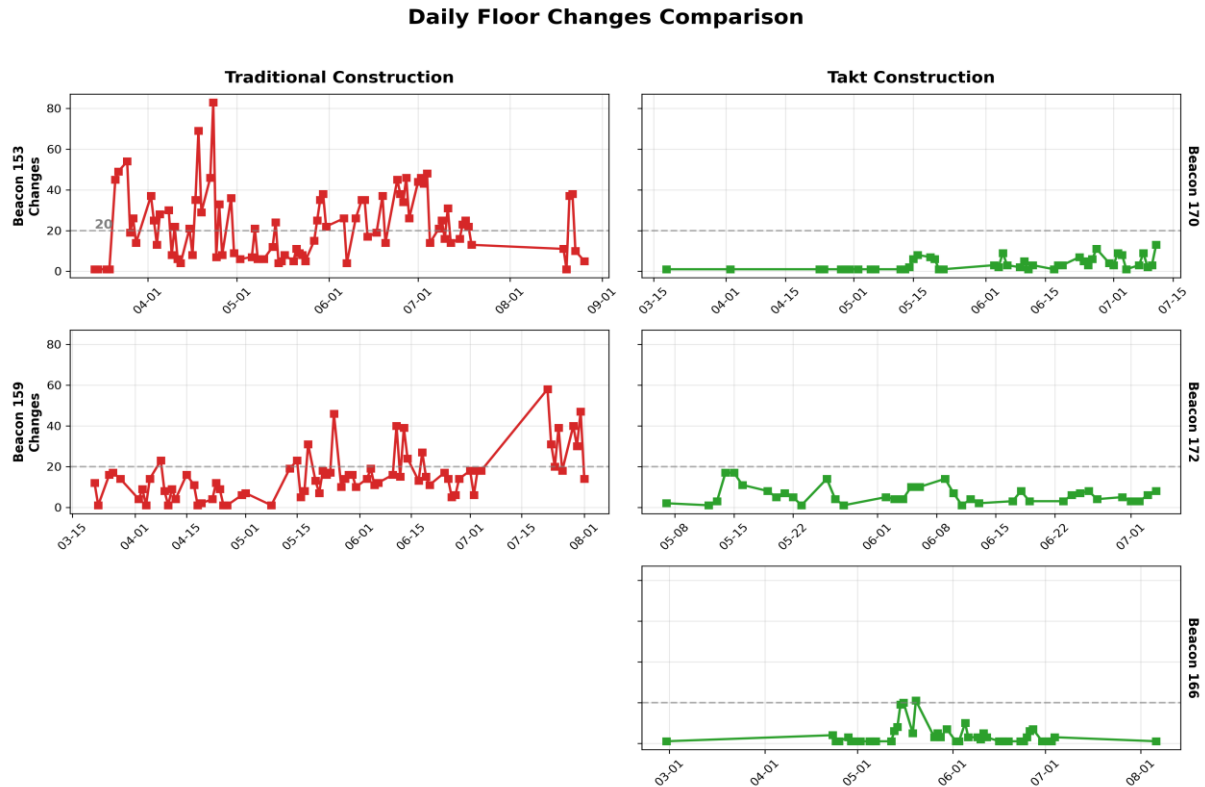


Figure 2: Floor Change Frequency of workers in the Traditional Project

Figure 4: Floor Change Frequency of Workers in Takt Project

ANALYSIS OF DAILY PRESENCE ON THE SITE

The daily presence of the workers varied on both sites, which is evident in Figure 5 and Figure 6, in a parallel comparison.

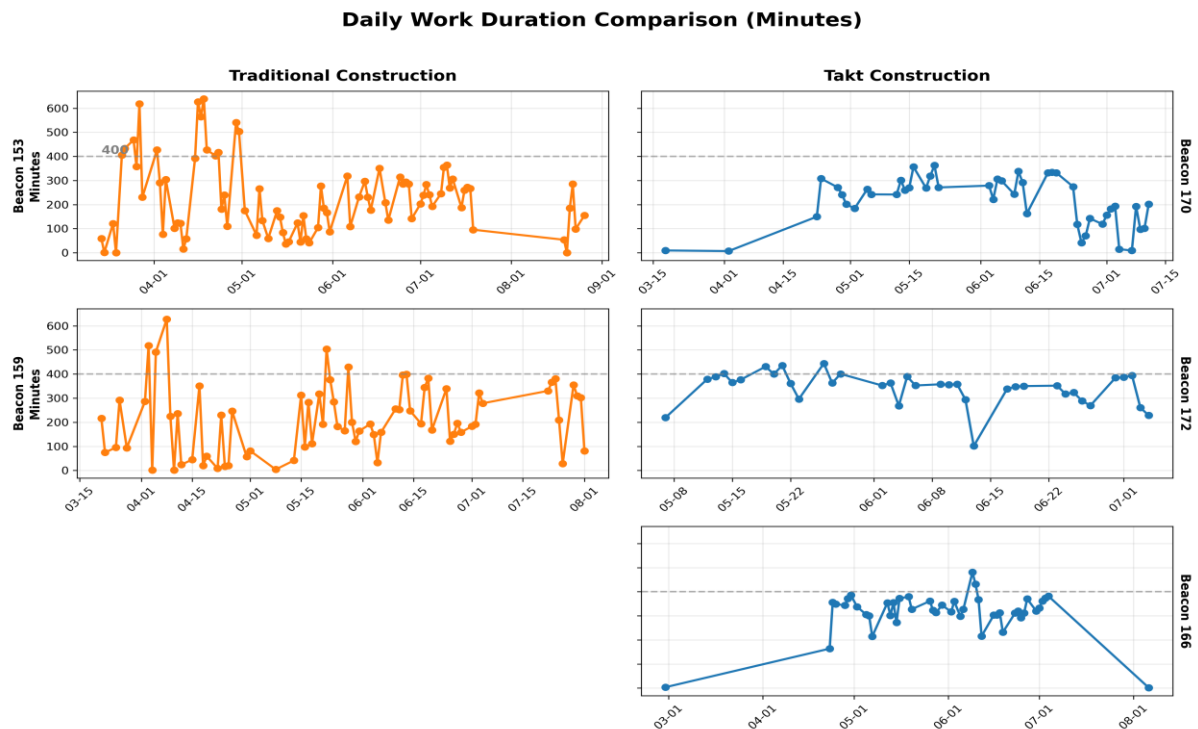


Figure 3 Daily Work Duration for workers in the Traditional Project

Figure 4 Daily Work Duration for Workers in Takt Project

Figure 5 shows the total time workers spent on the site in a traditional project. Workdays were highly irregular and elongated. The recorded work duration for both workers varied wildly. The maximum work time for both workers remained in normal duration, i.e., 7 hours in most of the cases. However, 10 occasions show more than 8 hours of continuous presence, indicating overtime or long wait. In parallel, Figure 6 shows the result for the takt project. It demonstrates that workers maintained a consistently uniform daily schedule that remained within standard working hours. All three workers began their shifts at 07:00 and completed their work at 15:30, with a regular lunch break. This pattern suggests that workers had more consistent working hours and did not engage in any overtime work.

ANALYSIS OF FLOOR-WISE PRESENCE PATTERN

The heatmaps shown in Figure 7 for SPR 159 and SPR 153, show a scattered and discontinuous presence across the building floors in the traditional project. The worker 159 spent the overtime days mostly on the 1st floor, where the main workshop was located. The pattern of his presence shows that the worker 159 was mostly handling workshop tasks. Worker 153 was the main worker who worked mostly on the upper floors, except for the 6th floor, where worker 159 worked in the last days.

The heatmaps for all three HVAC workers of the takt project show a clear, sequential, and harmonious flow throughout the progression of floors shown in Figure 8. A typical pattern for the crew was a continuous presence on Floor 3, followed by Floor 4, then Floor 5, and Floor 6.

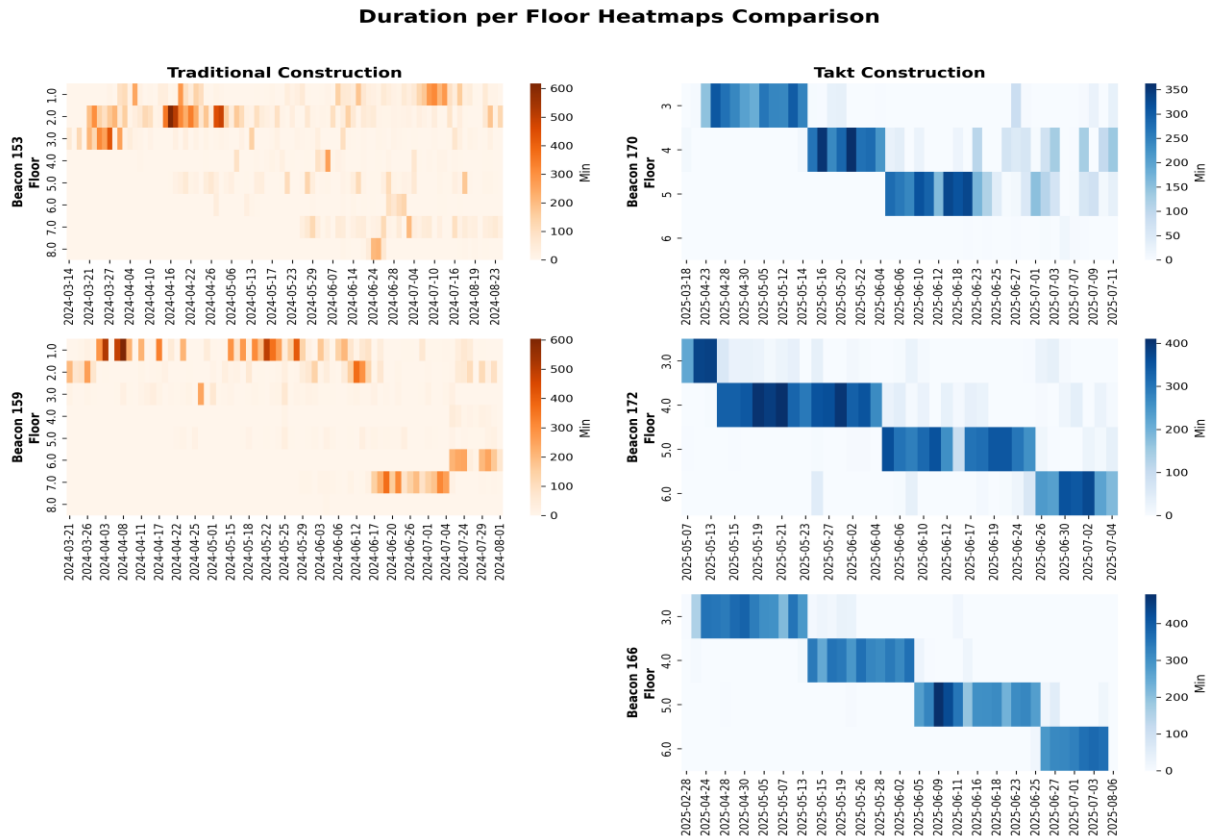


Figure 7: Floor-wise Presence Pattern of Workers in the Traditional Project

Figure 5: Floor-wise Presence for Workers in Takt Construction

DISCUSSION

This study aimed at a comparison of worker movement patterns between a traditional and a takt production case. The purpose was to learn how the production planning and control method might affect the movement patterns and how these patterns might relate to productivity. The comparison considered several features as proxies for productive work, and the results are summarized in Table 2. The comparison of the two cases suggests that takt production is associated with improved the trade flow. This result aligns with prior qualitative research (for example, Lehtovaara et al. (2021)), which reported the same effect and linked it to improved production performance.

The movement pattern shown in Figure 7 and Figure 8 reinforces this finding with quantitative measures. No logical sequential flow can be seen in the traditional worker's pattern of movement. Workers are frequently backtracking and moving between non-adjacent floors. Contrary to that, the presence pattern closely reflects the Takt plan in action. Each worker follows the same logical, forward-moving sequence with little backtracking. However, some backtracking is still visible in Figure 8, especially for worker 170, who regularly returned to the fourth floor after completing work on the fifth floor. This recurring pattern may indicate incomplete prerequisite work, material dependencies between floors, or a shared resource such as a workshop or storage area located on the fourth floor. This suggests that even within a takt-controlled environment, localised disruptions to sequential flow can persist. It should also be noted that IPS data captures worker presence and movement between zones but does not distinguish between productive and non-productive activities within a zone.

The comparison also indicates that crews changed floors much less frequently in the takt production case. Previous research has identified frequent or unnecessary location changes as

wasteful (Sacks et al., 2017). The maximum number of floor changes by the workers in traditional methods is more than 80 times per day (Mean: 22.3, SD = 14.9), which appears notably high compared to the takt case (Mean: 3.6, SD = 4.3). Conversely, in takt construction, workers spent most of their time in their designated work areas without wasting time travelling between floors. This reflects the pull-based production system, in which materials and information are delivered at the point of use, enabling workers to maximize their time on task. While reduced floor changes and backtracking indicate fewer disruptions, which previous research has associated with higher labour productivity (Neve et al., 2020; Sacks et al., 2017), a direct link between harmonious flow and productivity output cannot be established from movement data alone.

Table 2: Direct Comparison: Takt vs. Traditional

Feature	Case 1: Traditional (Sprinkler)	Case 2: Takt (HVAC)
Trade flow	Irregular and fragmented.	Stable, consistent, and predictable.
Floor change frequency	Range: 0–82 changes/day Mean: 22.3 (Standard Deviation (SD) = 14.9)	Range: 0–20 changes/day Mean: 3.6 (SD = 4.3)
Spatial coordination (heatmap)	Scattered and discontinuous presence with frequent backtracking. 18.18 re-visits/day (SD = 13.71)	Sequential and progressive flow with limited backtracking. 2.53 re-visits/day (SD = 3.67)
Daily work duration	Unstable Mean: 4.63 hours (SD = 2.07) Range: 1.69h–10.65h	Stable Mean: 5.11 hours (SD = 1.28) Range: 1.69h–8.01h
Team synchronisation	Limited. Workers show largely independent and unsynchronised movement patterns.	Coordinated. Workers show synchronised sequential progression across floors.
Production control	Movement patterns suggest production driven by immediate task availability.	Movement patterns are consistent with a predefined takt plan.

The movement pattern measurements also allow comparing the daily work durations (Figure 5 and Figure 6), which may reflect stressfulness for workers. The traditional case shows higher variability in daily presence (SD = 2.07) compared to the takt case (SD = 1.28), suggesting less predictable working conditions.

Overall, the movement patterns in the takt case appear planned and controlled, while the traditional case appears reactive. While previous research has so far addressed takt production control mostly qualitatively, studies such as Binnering et al. (2017) suggest that it provides a solid basis for flexible adjustments. The findings of this study support this view, despite small variations in worker movements. The difference in movement patterns could, however, also be explained by causes other than takt production. For example, a difference in the amount of preparation, project organization, contractual structure, complexity of the building, or availability of support functions, such as supply chain management, could also conceivably explain the difference. Nevertheless, takt production has also been suggested as being the common denominator for bringing the various benefits together (Riekk et al., 2023).

CONCLUSIONS

According to the analysis through IPS, the findings suggest that traditional construction methods are characterised by a less organised and reactive approach to managing daily tasks and project activities. The movement patterns indicate disconnected workflow that requires workers to move between different floors, resulting in extended daily worktime and potentially

wasted efforts. In contrast, Takt indicates a consistent pattern to trade flow that enables workers to follow a predetermined “Takt” or rhythm. The data suggests that workers operate on a regular daily pattern, remain within the same zone, and maintain a consistent pace in their work.

This study contributes to the body of knowledge by bridging two previously separate research streams, BLE-based worker tracking and takt production analysis, to provide the comparison of individual worker movement patterns across different production systems. The findings offer quantitative support which was previously described qualitatively that takt production is associated with more stable and predictable operational flow at the worker level. The descriptive metrics introduced in this study, floor change frequency, backtracking rate, and daily presence variability, provide a replicable framework for future researchers to assess operational flow across different production environments.

For lean construction professionals, these metrics can also serve as a diagnostic tool to identify flow disruptions and assess the effectiveness of production control in real time. Furthermore, the high floor change frequency and backtracking observed in the traditional case highlight the importance of co-locating materials, tools, and information within designated work zones to reduce unnecessary movement. Furthermore, the consistency of daily work duration in the takt case suggests that structured production planning may contribute to more predictable and sustainable working conditions

LIMITATIONS AND FUTURE WORK

The research can be further extended by validating the efficiency using takt construction through workers’ experience, as depicted in the results. The current study compares two different types of construction facilities (a sports arena and a hospital) for two trades (HVAC and sprinkler), which is a limitation of the current study. The comparison between two similar projects (in terms of project context, size, function, floor number, and tracked trades) can provide a more reliable comparison of the production systems. It is suggested to conduct future studies on similar layout facilities.

The number of tracked workers was limited to two and three per site, respectively, which restricts the generalizability of the findings. Although beacons were distributed to a larger number of workers across both projects, many carried them only briefly or inconsistently. The workers included in this study were selected because they provided the longest continuous tracking periods. The study draws on over 13,900 data points collected continuously over six months. Descriptive statistics, including means, standard deviations, and ranges, were used to characterise the variability and consistency of these patterns across both cases. Inferential statistical tests were not applied, as the small number of tracked workers per case does not meet the minimum sample size assumptions required for meaningful significance testing. Future studies with larger worker samples and inferential statistical analysis are needed to validate these preliminary findings. While this study followed ethical protocols including ethics review, informed consent, and data anonymisation, future studies involving worker tracking at larger scale should continue to prioritise transparent communication about data usage and worker privacy.

FUNDINGS

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