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HARMONIZING CONSTRUCTION FLOW: INTEGRATING TAKT PLANNING, WORKSPACE MANAGEMENT, AND LOOKAHEAD STRATEGIES

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ABSTRACT

This paper explores an approach that integrates takt planning with real-time workspace utilization metrics to enhance its effectiveness and support improved lookahead planning. The proposed workflow leverages automation and innovative metrics to represent dynamic workspace conditions, incorporating non-permanent elements such as scaffolding, material storage, and temporary clutter, factors often overlooked but critical to construction performance. These metrics facilitate the definition of takt zones, aligning work allocation with spatial availability. By correlating the spatial positioning of these elements with worker productivity derived from prior site performance data, the study develops a framework for mapping takt zones. This framework enables planners to create lookahead plans that strategically allocate activities within zones, optimizing productivity. The methodology is validated through a sample project, demonstrating its effectiveness in structuring workflows and providing actionable insights for efficient resource allocation. The findings highlight the synergy between takt planning, lookahead planning, and digitization, underscoring the value of integrating workspace and productivity data into workflow optimization. This research contributes a practical, data-driven approach to improving construction planning.

KEYWORDS

Lean construction, Construction digitization, Lookahead, Takt planning, Workspace utilization

INTRODUCTION

Effective forecasting and planning are critical for the success of construction projects, which are often characterized by complex, multifactorial processes and interdependent tasks. Accurate predictions of task performance and sequencing enable project managers to mitigate delays, optimize resource allocation, and ensure timely project delivery. Takt planning has gained significant attention in construction as a method of implementing lean principles. It is designed to create structured workflows and improve productivity. However, as projects progress and construction conditions become increasingly complex, takt planning has shown vulnerabilities, particularly during the later stages of construction (Alhava et al., 2019). This has highlighted the need for digitization and enhancement to ensure its sustained effectiveness (Babanina, 2020)

To address these challenges, several attempts have been made to integrate takt planning with digital tools such as Building Information Modeling (BIM) (Babanina, 2020; von Heyl &

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Teizer, 2017). Digitization not only reduces the vulnerability of takt planning but also strengthens its connection to real-world construction scenarios by facilitating situational awareness (Halttula & Seppänen, 2022). Tommelein & Emdanat, (2022) further emphasized that effective takt planning relies on accurate, detailed data representing production rates and work density, which are often highly context-specific and vary depending on project characteristics. They proposed a framework for improving takt planning through lean principles, underscoring the potential for automation and synchronization with digital tools to enhance its efficiency (Gonzalez et al., 2022).

Building on this foundation, this study explores a way to form a construction lookahead through enhanced takt planning, which integrates information obtained from digital tools representing workspace utilization conditions. The proposed methodology incorporates spatial utilization metrics to define takt zones dynamically and aligns work allocation with actual space availability. By leveraging historical productivity data, the enhanced approach maps the relationship between space utilization and worker productivity, enabling planners to allocate activities strategically and maximize performance. The historical data used in this study refers to previously recorded productivity and spatial information during the execution of comparable construction activities from earlier phases or similar projects. To evaluate its effectiveness, the enhanced takt planning method was tested on a sample construction project.

LITERATURE REVIEW

Takt planning has shown promise in bridging the gap between long-term schedules and actionable short-term plans. Recent studies have explored integrating takt principles into the Last Planner System (LPS®) to improve workflow reliability and resource allocation (Frandson et al., 2014). By defining takt zones and aligning tasks with specific space and time constraints, takt planning enhances predictability in construction activities (Tommelein & Emdanat, 2022). Efforts to incorporate takt into lookahead planning often aim to resolve constraints and dynamically adapt plans to site-specific conditions (Emdanat et al., 2016). Takt planning focuses on the overall project rhythm, while lookahead planning addresses short-term operational needs. Their integration can support alignment between macro-level schedules and micro-level execution. However, integrating these methodologies remains challenging due to the lack of real-time spatial data and automated tools for accurate task sequencing (Halttula & Seppänen, 2022).

LOOKAHEAD PLANNING AND AUTOMATION

The LPS®, introduced by Ballard & Howell, (1997) is a cornerstone of Lean construction principles aimed at improving planning reliability and reducing inefficiencies in construction processes (Heigermoser et al., 2019; Heigermoser & Garcia de Soto, 2022). Among its components, lookahead planning bridges long-term master schedules with short-term executable plans by resolving constraints and ensuring task readiness within a 3- to 6-week timeframe (Ballard & Howell, 1998). Despite its value, manual lookahead planning is time-intensive, prone to errors, and struggles to adapt to real-time changes on dynamic construction sites, such as material shortages or weather disruptions (Mengiste et al., 2023). These limitations have driven research into automation to enhance its efficiency and reliability. Automation in lookahead planning leverages advancements in machine learning, computer vision, and data analytics. For example, Zeng et al., (2023) integrated building information modeling (BIM) can improve supply chain tracking and predict disruptions, while Amer et al., (2021) used natural language processing (NLP) to align master schedules with short-term plans. Their model generated detailed lookahead plans by analyzing activity descriptions and exploring logical dependencies between tasks. However, this method relied on specific training data, introducing potential biases and limiting its generalizability.

Mengiste et al., (2023) proposed a forecasting method using a Gated Recurrent Unit Recurrent Neural Network (GRU RNN). Their approach analyzed temporal data on material appearances to predict achievable outcomes over upcoming weeks. By considering factors such as space utilization and resource allocation, dynamic site conditions and non-visual constraints like worker skills and material delivery schedules were captured. While effective, it required regular retraining to accommodate new variables and evolving site conditions, reflecting the dynamic nature of construction projects. Moreover, their method entirely depends on past information and does not provide enough flexibility and control to the project management team.

TAKT PLANNING IN CONSTRUCTION

Takt planning aligns workflows with demand to create a balanced production rhythm, reducing bottlenecks and enhancing efficiency (Tommelein & Emdanat, 2022). It relies on data inputs such as production rates, crew capabilities, and spatial constraints, making it highly context-specific. Effective takt planning depends on accurate spatial and temporal representations of construction activities to optimize task sequencing and mitigate delays.

According to Tommelein & Emdanat, (2022) traditional takt planning (approaches summarized in Table 1), such as Location Breakdown Structure (LBS) (Iii et al., 2020), Standard Space Units (Binninger et al., 2017) and Work Density Methods (WDM) (Tommelein, 2022), focus on dividing projects into zones or grids to balance workloads. These methods, while effective for standardizing workflows, often require iterative refinement and rely on static assumptions about zone characteristics and resource needs. For example, LBS assumes uniform resource needs across predefined zones, while WDM requires extensive data collection and analysis to optimize zones iteratively. These limitations highlight the need for integrating automation and real-time data into takt planning frameworks.

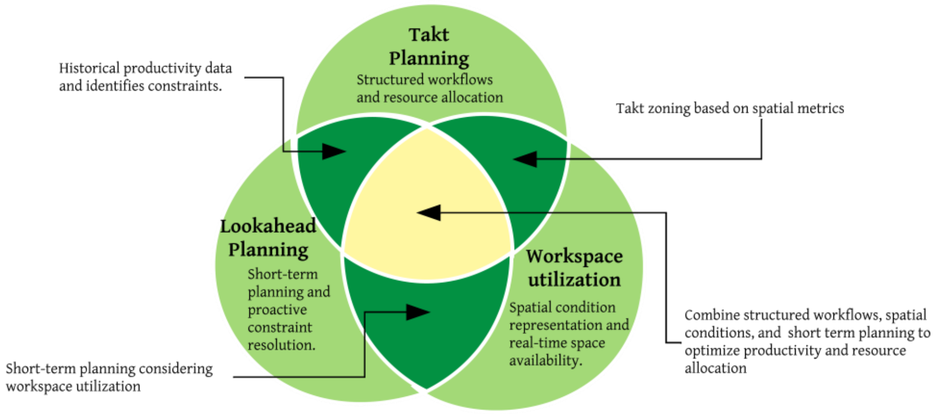

Figure 1: Intersections and synergies among takt planning, lookahead planning, and workspace utilization (source: the authors)

Figure 1 illustrates the critical interplay between Takt Planning, Lookahead Planning, and Workspace Utilization, emphasizing their combined potential to optimize construction workflows. Figure 1 underscores how structured workflows and spatial task zoning, foundational to Takt Planning, can align with the proactive constraint resolution and short-term readiness of Lookahead Planning. Additionally, considering the role of Workspace Utilization as a constraint emerges as a significant factor, providing actual spatial representations that support both planning methodologies. The convergence of these elements highlights the need for an integrated approach that harmonizes macro-level rhythms with micro-level adjustments. While the literature identifies Takt Planning's capacity to structure workflows and Lookahead Planning's adaptability to dynamic conditions, their integration remains underexplored. Figure

1 suggests that combining these strategies, underpinned by real-time spatial data and automated tools, offers a pathway to bridge existing gaps in construction planning. This integration serves as a point of departure for further research into developing a cohesive framework that balances project rhythm with operational flexibility.

Table 1: Summary of Takt planning approaches

Approach	Description	Limitations	Assumptions
Location Breakdown Structure (LBS)	Divides project into predefined zones using location hierarchy. Assesses work in each location, aiming for sequence and consistency.	Predefined zones may need adjustment, limiting flexibility. Sequential flow can delay tasks if one zone encounters issues.	Assumes zones and sequence are fixed; all zones have similar resource needs and durations.
Standard Space Units (SSU)	Breaks work into smaller, consistent units (e.g., rooms or offices), defining trade durations per unit.	Ineffective for projects with irregular or non-repetitive spaces. Assumes high levels of standardization.	Assumes work units are homogeneous and trades can repeat tasks consistently.
Block Planning	Divides the project into fixed time-space blocks (e.g., 5-day blocks) to coordinate multiple trades within each block.	Requires trades to adjust crew sizes to fit block durations, increasing costs. Rigid block definitions may not fit all tasks or workflows.	Assumes trades can scale up/down crews and adapt tasks to fit the fixed takt block.
Work Density Method (WDM)	Divides work into fine-grained grids based on production rates and density. Optimizes zones iteratively using data collection.	Time-intensive to collect and analyze data. Requires advanced planning and iterative refinement.	Assumes accurate data collection and analysis for workload balancing.

Integrating takt planning into lookahead processes, supported by digitalization, offers a promising solution to the challenges of traditional planning approaches. By combining the structured workflow of takt planning with the adaptability of automated lookahead forecasting, construction planners can address site-specific constraints and optimize performance. This study builds on these insights by proposing an enhanced takt planning framework that incorporates spatial utilization metrics and evaluates its effectiveness in a sample construction project. The findings aim to provide actionable insights into the complementary roles of takt planning, lookahead planning, and automation in optimizing construction workflows.

METHODOLOGY

The approach proposed in this work follows the proposed takt planning based framework presented in Figure 2. The flowchart begins with the initialization of construction and incorporates the originally developed construction execution plan (master plan). If the construction work is in its initial stage, this could involve a takt plan. In such cases, the lookahead plan for executing activities in the upcoming weeks is directly derived from the master takt plan, assuming a fresh workspace where all constraints have been accounted for. As construction progresses, workspace conditions evolve, making it essential to consider these changes when estimating the next set of tasks and developing an executable lookahead plan.

The initial step is extracting the next set of tasks from the master plan and evaluating the feasibility of the work in terms of space constraints. Hence, this step requires the development of an equation to relate the work productivity with the space availability using the historical performance of the site. The closeness metric is quantified as the distance from the centroid of workspace occupying elements to the construction element is used to represent space availability in the equation. For example, suppose the centroid of a pile of construction materials is within a small distance from the wall under construction. In that case, the available workspace for workers is constrained, negatively impacting productivity. These distances are then mapped to productivity values derived from historical site-specific data, which quantify the percentage change in work completion per day under varying workspace conditions. The productivity vs. space relationship is modeled through regression equations, enabling planners to predict task performance in each zone based on actual workspace metrics.

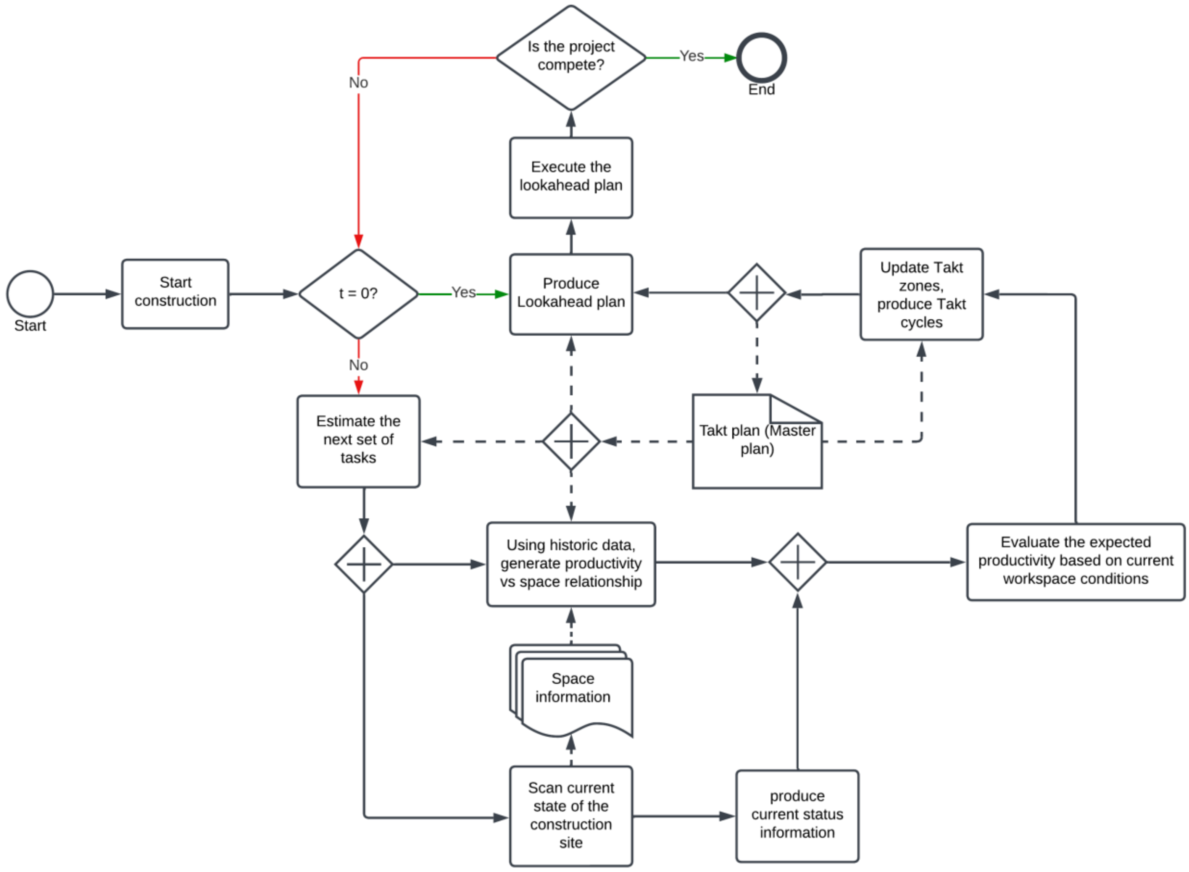

Figure 2: General process of the proposed methodology

Workspace utilization metrics play a critical role in generating lookahead plans, which bridge the gap between the master takt plan and short-term execution. By analyzing current workspace conditions and past productivity trends, the system ensures that upcoming tasks are planned to maximize efficiency. As shown in Figure 2, this relationship informs the evaluation of current workspace conditions. These changes and updates are reflected in the flowchart under “Update Takt zones, produce Takt cycles”. Using actual data and the regression-based productivity model, the system recalibrates the takt plan as well as the lookahead plan to reflect current workspace conditions.

In LBS (Iii et al., 2020) and SSU (Binninger et al., 2017), predefined zones or hierarchical location divisions are commonly used. In our methodology, spatial zones are not predefined or based on static spatial divisions; rather, they are delineated dynamically based on empirical patterns observed in construction performance and workspace occupancy. As illustrated in Figure 3, the x-axis represents the central location of workspace-occupying elements (in meters), and the y-axis shows the percentage completion of a representative construction task. Clustering and noticeable shifts in performance distribution across the horizontal axis suggest distinct behavioral patterns within different spatial intervals. These inflection points (i.e., where task performance distributions change) serve as natural boundaries for segmenting the space into zones (e.g., Zones 1 through 5). This approach allows for the identification of localized areas with distinct productivity characteristics. Unlike arbitrary or uniform zoning, this data-driven segmentation reflects actual performance variability, enabling a more nuanced understanding of the interplay between spatial occupation and task progress. Consequently, this flexible zoning method supports more informed planning and scheduling decisions by capturing spatiotemporal dynamics in construction environments.

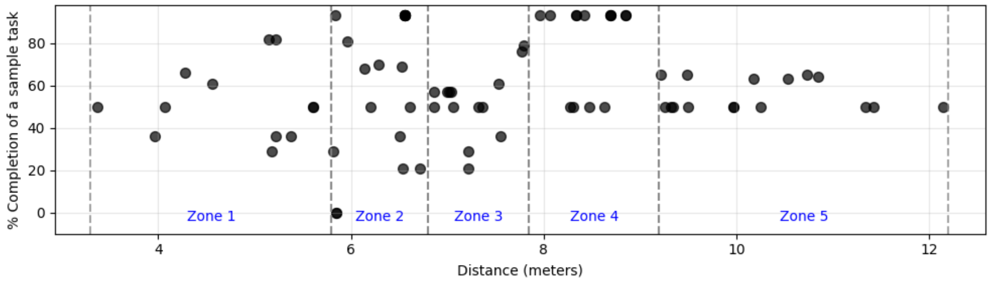

Figure 3: Distance of occupying elements vs. % task completion, with zones indicating different activity performance patterns

Figure 4 shows a theoretical takt plan developed before the start of construction, in which the workspace is divided into predefined zones (Zone 1 to Zone 5) and assigned scheduled work packages (Work Package 1 to Work Package 4) with specific durations (D1 to D4). These initial assignments are based on simplified assumptions of uniform site conditions and consistent productivity. For example, in the takt cycle highlighted by the red bounding box in Figure 4, Work Package 4 is scheduled to occur in Zone 1 for a duration of D4. However, as construction progresses, real-time site data (e.g., from laser scanning and 360-degree imagery) reveal deviations from these initial assumptions. For instance, Zone 1 becomes partially obstructed due to material deliveries and scaffolding, reducing accessible workspace and extending the duration required for Work Package 4, thereby disrupting the takt cycle. Affected work packages are marked with red bounding boxes to indicate tasks impacted by updated workspace conditions. To address this, the proposed system quantifies spatial constraints using a 'closeness' metric, which feeds into a predictive model that correlates workspace conditions with task productivity, enabling informed adjustments to takt cycle durations.

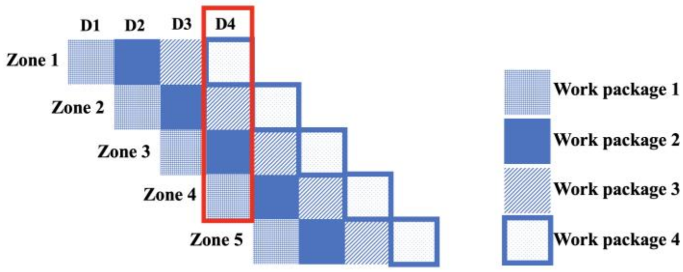

Figure 4: Theoretical takt plan showing the initial assignment of work packages to zones

The model detects a projected decline in productivity for Work Package 4 in Zone 1. In response, the system dynamically updates the takt plan: Zone 1's activities are temporarily deprioritized, and resources are reallocated to Zone 2, where current conditions support higher efficiency. Meanwhile, the lookahead schedule is revised, lower-space-requirement tasks are temporarily assigned to Zone 1, and Work Package 4 is rescheduled for a later cycle when spatial conditions are expected to improve. Thus, the figure conceptually supports the methodology by showing how static plans evolve based on real-time spatial and productivity feedback.

By enhancing takt planning to incorporate zones that reflect real workspace conditions, productivity in high-performing zones can be maximized, thereby increasing overall value and minimizing wasted effort in less productive zones. Planners can also dynamically improve the conditions on the construction workspace and this could result in reshuffling zones. This process enables workers to focus and prioritize activities. The defined relationship between the zones and productivity increases standardization and batching of construction work (Frandson et al., 2014).

CASE STUDY

A construction project consisting of multiple rooms used as laboratory and office spaces was used to demonstrate the proposed takt-lookahead-workplace utilization workflow (for more details about the project, readers are referred to Mengiste et al., (2023)). The planned schedule of the work is presented in Table 2. The concrete masonry work was planned to be completed in 19 days, starting from Jan 1, 2022. The work included building a 37.6 square meter area of block work. Following the completion of this task, work on two different tasks, Electrical works and Finishing (plastering and painting), was planned to start. Electrical work had three sub-tasks. The first sub-task was the installation of conduits and trays. This sub-task included installation of 44 m of conduit, starting on March 19, 2022 and a duration of 37 days. The second sub-task was wiring and cabling. On this subtask, 44 meters of wiring and cabling work was expected to be conducted in 54 days, starting from April 01, 2022. The last sub-task in the Electrical work was the installation of distribution boards (DBs) and fixtures. This task included the installation of one DB, two sockets, and one switch. According to the construction execution plan, finishing and plastering work started in parallel with electrical works. There were two sub-tasks under finishing works. The total of 37.6 square meters of surface was plastered and painted in 45 and 30 days, starting March 01 and April 15, 2022, respectively.

Table 2: Task details of the sample project

Tasks	Quantity of work	Units	Planned Start	Planned End	Planned Duration	Budget	Actual Start	Actual percentage completion
Construction of concrete masonry wall	**37.6**	**sq. m**	**1-Jan-22**	**20-Jan-22**	**19 days**	**$3,760.00**	**1-Jan-22**	
Electrical works								
Conduits and trays installation	44	m	19-Mar-22	25-Apr-22	37 Days	$2,200.00	25-Apr-22	100%
Wiring and cabling	44	m	1-Apr-22	25-May-22	54 Days	$3,080.00	25-May-22	100%
Fixing DBs and Fixtures	4	pcs	28-Jun-22	6-Jul-22	8 Days	$120.00	22-Jul-22	93%
Finishing work								
Mortar plastering	37.6	sq. m	1-Mar-22	15-Apr-22	45 Days	$3,158.40	15-Apr-22	100%
Painting	37.6	sq. m	15-Apr-22	15-May-22	30 Days	$2,820.00	15-May-22	64%

The project performance and visual data collected until June 9 were used for training and productivity understanding. Data that is collected after June 9 until July 18 is used as ground truth and testing. By June 9, all of the tasks, except painting and Fixing DBs and Fixtures, were complete. The daily collection of 360 images and routine laser scans were used to produce a relationship between activity execution percentage and site space utilization data. The construction site is divided into five zones (Zone 1 to Zone 5) based on spatial distance from the center and variations in task performance. The distances corresponding to each zone are defined as follows: Zone 1 (0.0–5.80 meters), Zone 2 (5.80–6.80 meters), Zone 3 (6.80–7.85 meters), Zone 4 (7.85–9.20 meters), and Zone 5 (9.20–12.20 meters). The boundaries between zones are assigned subjectively based on logical and reasonable criteria. In this case, the zones are selected to capture distinct productivity characteristics, allowing for a detailed analysis of spatial dynamics and task progress. In general, these zones provide a structured framework for analyzing site productivity, while the given range of values can be adaptable for different project needs. To create a dynamic Takt plan for completing the remaining tasks, it is essential to define construction execution performance. This requires establishing a relationship between the distance (i.e., the position of the space-occupying elements measured from the construction element) and the daily increase in the percentage completion of each unfinished task. For Fixing DBs and Fixtures and Painting, that is reflected in Equation 1.

$$P_i = \begin{cases} 0.0021d + 0.0284 & \text{for Fixing DBs and Fixtures} \\ -0.0031d + 0.0314 & \text{for Painting} \end{cases} \quad \text{Equation 1}$$

Where *Pi* indicates the daily increase in percentage completion for activity *i* and *d* is the distance (meters) from the construction area (e.g., wall) to the location of the space-occupying elements (e.g., scaffolding).

Figure 5 provides a representation of workspace zoning and its relationship to the physical elements of the construction site. Figure 5(a) shows the floor plan of the workspace for wall construction, divided into five zones mapped outward from the wall under construction. This zoning scheme facilitates the spatial categorization of activities and productivity. Figure 5(a) also introduces the concept of a workspace-occupying element, with the distance measured from the wall to the centroid of the occupying element, offering a spatial metric to assess workspace impact. Figure 5(b) presents a volumetric representation of occupying elements within the site (red overlay), showcasing their distribution and potential impact on workspace utilization. Figure 5(c) shows a real-world example of the construction site, highlighting the workspace (floor area) and the wall (element) under construction, with a green overlay indicating workspace boundaries.

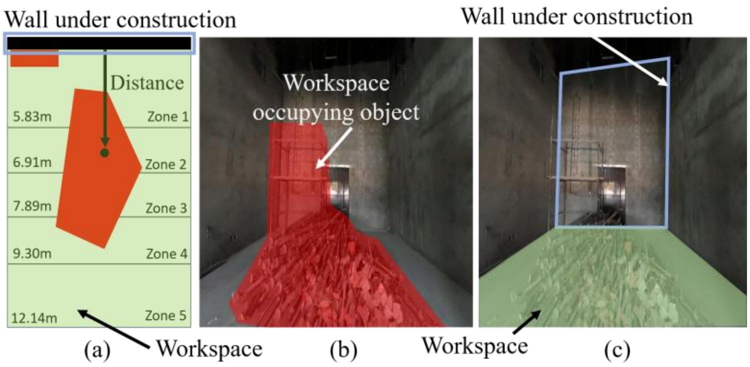

Figure 5: Workspace zoning and its relationship to site elements. (a) Floor plan with five zones mapped from the wall under construction and workspace-occupying elements. (b) Volumetric representation of occupying elements. (c) View with workspace boundaries highlighted.

RESULTS AND DISCUSSION

The integration of flexible takt planning, based on the spatial utilization of takt zones, demonstrates the potential to enhance workflow synchronization and efficiency on construction sites. By leveraging the derived equations (Equation 1) to compute P_i (daily increase in percentage completion of tasks), the study highlights the relationship between task progression and spatial constraints. Using the upper and lower ranges of the zones and the defined set of equations (Equation 1), the daily increase in percentage completion (upper and lower bounds) is calculated. The results of this process are presented in Table 3. The remaining % of work (W) is calculated using the actual percentage completion information from Table 2 (100-"Actual percentage completion"). The upper (U) and lower (L) bounds represent the expected range of daily percentage work completion within a given zone, considering workspace utilization as the primary constraint. This assumes that other potential construction constraints, such as material supply, labor availability, and environmental factors, do not impact progress.

The results in Table 3 illustrate contrasting trends across different tasks and zones. Zone 1 consistently outperformed the other zones for Paint and performed the lowest in Fix DBs and

Fixtures. For Zone 1, the average daily increase in percentage completion for Fix DBs and Fixtures is approximately 3.45%, while for Painting, it is around 2.24%. Based on these values, Fix DBs and Fixtures can be completed in about 2.03 days (7% ÷ 3.45%) if the elements remain in Zone 1, compared to about 1.3 days (7% ÷ 5.09%) in Zone 5, demonstrating improved efficiency when the occupying elements are placed at greater distances. Conversely, Painting requires about 16.1 days in Zone 1 but more than 280 days in Zone 5 due to the stagnation in progress, reinforcing the need for optimized workflows and strategic resource allocation. In the case of painting, Zones 4 and 5 exhibit significant inefficiencies, where progress nearly halts (see the L and U values of Zones 4 and 5 in Table 3). In Zone 5, the regression equation resulted in a negative value. To ensure realistic results, this value was set to zero, signifying a complete halt in work progress. In this context, a zero percent increase in completion indicates that no advancement is occurring, and the work remains stagnant. Without the adoption of new workflow strategies or process improvements, no progress is expected.

Table 3: Estimated daily work progress based on workspace utilization

Tasks	Remaining % of work (W)	Zones	Range of Distances (d)	Daily increase in % completion calculated using Equation 1 (P_i)			Average Projected number of days required to complete the task (W/A)
				Lower (L)	Upper (U)	Average (A) =(L+U)/2	
Fix DBs and Fixtures	7%	Zone 1	(0.00, 5.83)	2.84%	4.06%	3.45%	2.03
Fix DBs and Fixtures	7%	Zone 2	(5.83, 6.91)	4.06%	4.29%	4.18%	1.68
Fix DBs and Fixtures	7%	Zone 3	(6.91, 7.89)	4.29%	4.50%	4.39%	1.59
Fix DBs and Fixtures	7%	Zone 4	(7.89, 9.30)	4.50%	4.79%	4.64%	1.51
Fix DBs and Fixtures	7%	Zone 5	(9.30, 12.14)	4.79%	5.39%	5.09%	1.37
Paint	36%	Zone 1	(0.00, 5.83)	3.14%	1.33%	2.24%	16.10
Paint	36%	Zone 2	(5.83, 6.91)	1.33%	1.00%	1.17%	30.89
Paint	36%	Zone 3	(6.91, 7.89)	1.00%	0.69%	0.85%	42.55
Paint	36%	Zone 4	(7.89, 9.30)	0.69%	0.26%	0.48%	75.70
Paint	36%	Zone 5	(9.30, 12.14)	0.26%	0.00%	0.13%	280.16

From a takt planning perspective, the value of the information from Table 3 lies in its ability to guide the design of zone-specific takt intervals. For example, the high productivity in Zone 1 for painting suggests shorter takt times with minimal buffers, enabling rapid task completion. Conversely, the less productive zones require extended takt intervals and increased buffer times to accommodate reduced productivity and mitigate delays. The flexibility inherent in this planning approach allows teams to adapt takt sequences based on zone-specific productivity trends, ensuring continuous workflow and preventing bottlenecks. The results also provide actionable insights for resource allocation and task prioritization. Zone 1 consistently demonstrates optimal resource utilization, serving as a benchmark for improving productivity in lower-performing zones.

Meanwhile, Zone 5 presents significant challenges, especially for Painting tasks, where productivity drops drastically. In this example, Zone 1 represents non-building items occupying the workspace near the construction element. These items may include scaffolds, either assembled or unassembled. During the data collection period, assembled scaffolding was observed near the wall (Figure 5b). While scaffolding can obstruct activities that do not require it, its presence near the wall can benefit tasks such as painting higher sections. In such cases, the scaffolding enhances productivity by providing access and support for these tasks. A limitation of this research is its reliance on historical data, which may introduce bias due to variations between projects until a more comprehensive dataset is obtained. Furthermore, the proposed framework has not yet been tested in a complex construction site scenario; therefore, caution should be exercised when extrapolating or generalizing the results of this study. Evaluating the framework against traditional takt planning methods implemented on complex construction projects represents a valuable direction for future research.

In practical terms, integrating spatial utilization data with takt planning empowers project managers to optimize resource allocation and workflow sequencing by providing insights into real-time site productivity. This approach helps minimize downtime, reduce bottlenecks, and enhance overall efficiency by allowing targeted adjustments in task planning based on actual workspace conditions. Moreover, the digitization and automation inherent in the proposed method support continuous improvement in planning processes, highlighting opportunities for process enhancements, streamlined operations, and strategic decision-making to ensure more consistent project performance.

CONCLUSIONS AND FUTURE WORK

This study presents an integrated approach to harmonizing construction workflows by combining takt planning, lookahead planning, and workspace utilization metrics. The proposed methodology addresses challenges in the existing planning methods, such as static assumptions and inefficiencies in dynamic construction environments. By utilizing actual spatial data and historical productivity trends, the proposed methodology introduces adaptive takt zones that align task sequencing with real workspace conditions, thereby enhancing efficiency and optimizing resource allocation.

The results from the case study highlight the effectiveness of integrating workspace metrics into planning workflows. Tasks performed in areas with optimized spatial conditions (e.g., Zone 1) consistently outpaced those in constrained zones (e.g., Zones 4 and 5) for Painting and vice versa for Fix DBs and Fixtures tasks, emphasizing the pivotal role of workspace management in enhancing construction productivity. Additionally, the ability to recalibrate takt plans and lookahead schedules based on real-time data ensures continuous workflow synchronization and minimizes the risk of delays. The analysis underscores the practical value of dynamic takt planning, which adjusts to the changing spatial and logistical conditions of construction sites. It provides actionable insights for designing zone-specific takt intervals, prioritizing resources, and sequencing tasks to maximize productivity. Moreover, the framework emphasizes the importance of considering non-permanent elements, such as scaffolding and material placement, in construction planning, factors often overlooked but critical for site performance.

The findings from this study underline the potential of combining lean principles with digitization to achieve structured, efficient workflows in complex construction environments. Future research could explore the potential of the proposed methodology in large and complex construction projects, considering additional constraints such as resource availability. Further, future work could explore the automation potential of this framework, integrating additional real-time data sources, such as IoT devices and advanced imaging technologies, to refine productivity models and enhance decision-making capabilities.

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