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The Influence of Different Technical Approaches - A Comparison in Location-Based Management System and Takt Planning

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Abstract

Question: How do the methods LBMS and Takt planning differ in their technical approach? What influence does the different technical approach of the methods have on a project?

Purpose: This paper presents a detailed technical analysis of LBMS and Takt methodologies, extending beyond previous comparisons to examine their specific calculation techniques.

Research Method: Literature review and technical comparison of published formulations, followed by a simplified example and a real-project case study comparing duration and workforce metrics.

Findings: LBMS and Takt calculations are similar if work densities in locations are uniform, and buffers are not considered. LBMS favors time buffers to maintain continuity, while Takt relies on capacity buffers to maintain flow. If work densities vary between locations, the Takt approach shortens project durations but may cause resource fluctuations; whereas LBMS provides consistent resource distribution but typically results in extended project durations. In the case study, the Takt plan shortened the schedule by three weeks (~5%) compared to the optimized LBMS plan, while showing higher average workforce and stronger workforce variability.

Limitations: Empirical results are based on one real-project case study (single project sequence) and were not validated across multiple projects; generalizability is therefore limited. The analysis focuses on planning and does not model execution-phase control or cascading delay effects.

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Implications: Scheduling methods should be selected based on project-specific factors such as work densities and available resources. Understanding the technical differences enables more informed decisions – favoring Takt for flow efficiency in time-driven projects, and LBMS for stability in resource-sensitive environments.

Value for authors: This analysis reveals how buffer strategies affect both resource use and project durations. In addition, it provides a practitioner-oriented decision tree to support method selection based on project characteristics.

Keywords: Lean Construction, Location-based Management System, Takt, Buffering, Buffers, project duration

Paper type: Full Paper

Introduction

Lean Construction emerged from a critical reflection on traditional production models in construction. The traditional models emphasized transformation of inputs into outputs and neglected the continuity of work, interactions between processes, and social factors influencing performance (Mossmann, 2018; Abdelhamid, 2004; Abdelhamid et al., 2008). In construction practice, this predominantly technical and functional interpretation has contributed to inefficient workflows and frequent disruptions. Recurrent problems such as unreliable weekly work assignments have been identified as major sources of inefficiency and a barrier to sustainable improvement (Ballard, 2000; Abdelhamid, 2004).

In contrast, Lean Construction is understood as a comprehensive socio-technical production system that extends beyond waste elimination. In addition to transformation, Lean Construction considers flow and value in its underlying TFV-model (Koskela, 2000). Lean emphasizes continuous flow, coordination between processes, and learning across organizational and social dimensions (Mossmann, 2018). As a learning system, Lean Construction evolves through iterative feedback and adaptation to secure long-term value creation and efficiency (Abdelhamid & Copeland, 2022; Rother, 2009; Tapase, 2019).

Within this context, location-based planning methods have gained increasing importance in Lean Construction as a means of realizing reliable workflows in construction projects. Traditional activity-based planning systems insufficiently account for workflow within and between locations. Location-based methods, such as the Location-Based Management System (LBMS) and Takt planning, explicitly integrate spatial structure into scheduling and control, thereby enabling steadier production across locations and more efficient resource utilization (Olivieri et al., 2018). Takt planning aims to create a predictable and repeatable workflow by dividing projects into zones and assigning processes to fixed time intervals (Linnik et al., 2013; Dlouhy et al., 2016).

Previous research highlights different interpretations of flow within these methods. Some authors emphasize the continuity of labor moving through locations (Kenley & Seppänen, 2010; Sacks, 2016), while others focus on the flow of processes and their synchronization in time and space (Ballard, 2000; Tommelein et al., 2022). Comparative studies show that, although both LBMS and Takt planning aim to establish continuous flow, they differ fundamentally in their use of buffering, control mechanisms, and resource allocation strategies (Frandson et al., 2015).

These differences reflect an inherent tension between key project objectives. In Lean production, the ideal is to deliver exactly what the customer wants, instantly, and without inventory (Tommelein, 2015). However, achieving all three objectives at once is difficult in practice, as they are inherently in tension with one another. In the context of LBMS and Takt planning, this tension can be reframed along the dimensions of time, resources, and locations. LBMS prioritizes the continuity of resources across locations, whereas Takt planning emphasizes consistent process flow within locations (Frandson et al., 2015). How these priorities are balanced strongly influences project performance and the suitability of each method in different project contexts.

Both methods rely on different ways to visualize the schedule. LBMS uses flow lines to visualize resource movement across locations, while Takt planning deploys takt plans to represent the temporal sequencing of processes. Visualizations of the schedule are important to analyze as part of visual management (Tezel et al., 2016), but any location-based schedule can be represented in either visualization format (or even as a bar chart). Thus, analytic comparison of the technical aspects of these methods is required to really differentiate the methods.

Previous comparative studies of LBMS and Takt planning have remained largely qualitative and conceptual, without an explicit analysis of the underlying mathematical formulations or calculation logic (Frandson et al., 2015; Olivieri et al., 2016). This study advances existing research by providing a technical comparison of LBMS and Takt planning that explicitly examines their calculation structures at multiple planning levels. Recent developments in real-time resource tracking (Zhao et al., 2019), as well as advances in Building Information Modeling (BIM) and digital twins (Sepasgozar et al., 2021), further highlight the potential for data-driven analyses that integrate spatial and temporal dimensions of construction processes.

This study employed a quantitative research approach, examining published calculations of the two methods through a literature review. A brief explanation of both methods is introduced. Mathematical formulations of the examined methods are summarized and compared. First, a simplified calculation comparing two processes from a real project is presented to illustrate the core differences. Following this, a practical project sequence is analyzed to demonstrate the methods impact in a larger context. Detailed calculation steps and quantities are provided in the Appendix as a replication package to not exceed the paper's scope. Based on the results, a decision tree to help choose the right method for each project is presented.

Review of LBMS and Takt methods

In this section, the methods are examined in terms of their technical structure. The technical calculations of each method will be explained. The different operational mechanisms will be highlighted. This aims to analyze the multi-dimensional aspects of LBMS and Takt Planning, facilitating a comprehensive understanding of their respective attributes and divergences.

Location-based Management System

LBMS has its roots in the Line-of-Balance technique (Lumsden, 1968), which originated in production management. The line-of-balance (LOB) technique is a production planning and control method, particularly useful for projects with repetitive tasks like construction or manufacturing. It visualizes work progress using a single line on a graph, showing how tasks flow over time. LBMS augments CPM with location-based methods to address CPM's shortcomings related to repetitive tasks and production efficiency (Olivieri et al., 2017). The LBMS algorithm simplifies CPM schedules by concentrating on repetitive tasks, logistical patterns, and heuristics to facilitate a continuous workflow (Kenley & Seppänen, 2010). It aims to maximize productivity by planning continuous work, reducing waste and risk, increasing transparency, and enhancing predictability and flow (Kenley and Seppänen, 2010). Several case studies in real projects have been reported in construction literature (e.g. Kenley & Seppänen, 2010; Lucko et al., 2014; Seppänen et al., 2014).

Planning the schedule with LBMS starts with defining a location breakdown structure and determining a Bill of Quantities (BoQ) for each location. These BoQ items are lumped into tasks. The BoQ of a task explicitly defines all the location-specific activities that must be completed before a location is finished and the crew can proceed to the next location. Related BoQ items can be bundled into a task if they can be all done by the same crew, have the same dependency logic outside the bundle, and can be completed in a single location before moving to the next location (Kenley & Seppänen, 2010). A task's BoQ can consist of multiple items with differing units. Quantities can vary across locations. For instance, the task "Drywall" could include different kind of walls with different quantities in different locations. Most tasks repeat across multiple locations, with task placement determined by location-specific quantities. (Kenley & Seppänen, 2010).

Duration calculation of each location is based on the BoQ and assigned resources. In LBMS, labour consumption is a property of each BoQ item. It reflects the required worker and/or machine time (measured in hours) that it takes to produce one unit of each item (Kenley & Seppänen, 2010). The consumption value is based on assumptions of optimal crew composition (Arditi et al., 2002) and historic data (Kenley & Seppänen, 2010). Consumption rates are assumed constant in all locations, although differences in difficulty can be modeled with duration multipliers assigned to locations (Kenley & Seppänen, 2010). The default assumption is to do all work with the same crew. Task-level planning allows continuous resource utilization which avoids resource fluctuations, work mobilization and cascading delays, which would not be captured by focusing on individual activities in locations (Seppänen et al. 2014; Lehtovaara et al., 2020).

The total amount of work hours $h^T{}_j$ required to complete a location is the sum of the individual hours for each BoQ item in the task. The hours for each BoQ items calculated by multiplying the quantity in that location by the labour consumption rate for the item (Kenley

& Seppänen, 2010). Using hours as the unit of aggregation enables combing items varying units of measurement into a single task. The number of working hours is divided by the available crew size and the shift length (for example 8 hours per day). In each location n items are being grouped into a single task *i* (Kenley & Seppänen, 2010, p. 132). The calculation of task duration in each location is described in Equation 1.1:

(1.1)

$$h^T_j = \sum_{i=1}^{i=n} (Q_{i,j} \times R^C_{i,j})$$

$$D_{i,j} = \frac{h^T_j}{8\left[\frac{\mathrm{h}}{\mathrm{d}}\right] \times C}$$

Where:

h^T_j = Total hours for the location j

$Q_{i,j}$ = The quantity for item i, in location j

$R^C_{i,j}$ = The production rate for item i, in location j and where n items being grouped into a single task i

$D_{i,j}$ = Duration of task i in location j. Describes the time required to complete task i at location j.

$8\left[\frac{\mathrm{h}}{\mathrm{d}}\right]$ = 8 work hours per day

C = crew size

Calculating the start and finish dates of a task in LBMS schedule follows the CPM Forward Pass (Kenley & Seppänen, 2010, p. 147-149). The CPM Forward Pass calculates the Early Start and Early Finish values for each activity, along with the overall project duration. To achieve continuous workflow, the start date of a task in a location $ES_{i,j}$ should coincide with the end date of the previous location $EF_{i,j-1}$. The CPM algorithm is modified for tasks which are desired to be continuous. The later locations "pull" the start dates of earlier locations to be later, so that finish date of previous location equals the start date of later location. Planned time buffers *TB* are used to protect the continuity of work and function similarly to lags of CPM in planning phase (Kenley & Seppänen, 2010, p. 235 f.). The optimal buffer size for each task depends on the variability of its predecessor. The basic planning assumption is to keep the crew size C constant and allow the durations of locations to vary. The total duration $D_{i,total}$ of a task is the sum of the durations in all locations described in Equation 1.2:

(1.2)

1. CPM Forward Pass

$$ES_{i,j} = max(EF_{predecessor\ of\ i\ +\ TB})$$
$$EF_{i,j} = ES_{i,j} + D_{i,j}$$

2. LBMS Heuristic

$$ES_{i,j} = EF_{i,j-1} \text{ by delaying early locations}$$

3. Task Duration

$$D_{i,total} = \sum_{j=1}^{n} D_{i,j}$$

Where:

$ES_{i,j}$ = Earliest time at which a task *i* can begin at location *j*.

$max(EF_{predecessor\ of\ i})$ = Completion of the same task in previous location or a predecessor task in the same location.

TB = Time Buffer

$EF_{i,j}$ = Earliest time at which task *i* can be completed at location *j*.

$D_{i,j}$ = Duration of task *i* in location *j*.

$D_{i,total}$ = Total duration of a task *i* over all locations.

Takt planning

Takt planning originated from manufacturing. It refers to the heartbeat of assembly lines in the Toyota Production System (Haghsheno et al., 2016). The Toyota Production System is a manufacturing and management philosophy developed by Toyota to achieve optimal efficiency and eliminate waste by streamlining production processes. The main principle is to plan value-creating activities of equal duration across the entire process chain (Binninger et al., 2017). The activities are assigned with locations (takt areas) and the time in which the work package should be completed at a location (takt time) (Binninger et al. 2017a).

In the initial phase, one of the primary parameters is the identification of locations referred to as "Takt areas" (Binninger et al., 2017a). Takt areas are necessary to identify the scope of work and processes to subsequently divide these into work packages (WP). Previous research developed two approaches for the determination of takt areas. Tommelein (2014; 2022) introduced the concept of work density within the Work Density Method (WDM). Work Density serves as the unit to describe workload per zone and multiple zones as balanced work densities as possible for all trades are combined to takt areas (Tommelein, 2022). Binninger et al. (2017) propose calculating detailed quantities for a standard space unit (SSU) per defined functional area and then combining one or more SSUs to each takt area.

Both methods require defining the required processes. These processes, also called work steps, are bundled into WPs and result in the scope of work for each area. Each WP follows the traditional trade-based division of work according to trades so that there are clear responsibilities for a WP (Binninger et al., 2017). A WP can contain several work steps from one trade such as placing formwork, concreting, or installing fixtures. “Takt wagons” are formed by combining one or more WPs. They can be from different trades if they do not interfere with each during a predefined time unit (takt time) e.g. day, half-week, week. The “Takt train” is a sequence of “Takt wagons” which flow in logical order through takt areas in the beat of the takt time (Dlouhy et al., 2016). The “Takt train” is comparable to a continuous production line. Takt aims to optimize work packages and team sizes to fit the desired takt time, enhancing productivity and minimizing non-value-adding activities (Vatne & Drevland, 2016).

Binninger et al. (2017) introduced a formula to calculate the duration for an individual work package (Equation 2.1). The duration of a work package (D_x) is affected by the volume of work (V_x) and *t*. The labor consumption rate R_c which is based on historical data sets. Finally, the total hours are divided by crew size (cs_x) and workday length (by default 8 h). Crew sizes in Takt are typically determined separately for each work package depending on V_x (Binninger et al., 2017). The duration D_x of a work package is the sum of the required work hours depending on the work volume described in Equation 2.1:

(2.1)

$$D_x = \frac{V_x \times R^C}{8\left[\frac{\mathrm{h}}{\mathrm{d}}\right] \times C}$$

Where:

D_x = Average duration of work package x [in days]

V_x = Volume of work of work package x

$8\left[\frac{\mathrm{h}}{\mathrm{d}}\right]$ = 8 work hours per day

R_C = Labor consumption rate

C = crew size

Takt planning uses capacity buffers to protect the system from variability. The Takt time *TT* defines the time frame for a wagon. A wagon is the limit for each Takt. Therefore, the wagon duration corresponds to the selected Takt time and is specified and not calculated. Wagons include capacity buffers, which are included in the plan by underloading wagons by planning just e.g., 80-95% of their capacity (Frandson et al., 2015; Binninger et al., 2016). The duration of work packages D_x included in the wagon should not exceed the takt time, including the capacity buffer. If the load is uneven, work steps can be split into different work packages. These split packages are then rearranged into wagons, considering the constraints of different trades, to have sufficient capacity buffer of 5-20% in each wagon with as even load as possible. This levelling process is necessary for steady progress (Rother et al., 2003). The calculation of the required capacity utilization at wagon level is described in Equation 2.2.:

(2.2)

$$W_x \mathrel{\hat{=}} TT$$
$$W_x\text{: } 0{,}8 \leqq \frac{D_x}{TT} = CU_x \leqq 0{,}95$$

Where:

W_x = Wagon Duration *[in TT]*

D_x = Average duration of work package x [in days]

TT= Takt Time of production system [in days]

CU_x = Capacity utilisation (~80-95%)

The calculation of a Takt train is described in Equation 2.3:

(2.3)

$$T_x = W_{x1} + W_{x2} \ldots$$
$$T_{x,TT} = \frac{W_{x,\text{ overall}}}{TT} = 0{,}8 \leqq CU_x \leqq 0{,}95$$

Where:

T_x = Takt train *[in TT]*

W_x = Wagon Duration *[in TT]*

$W_{x,\ overall}$ = Duration of all Wagons of a Train *[in TT]*

$T_{x,TT}$ = Duration of a Takt train *[in TT]* including capacity buffer

CU_x = Capacity utilisation (~80-95%)

The duration formulas used for "Tasks" in LBMS and for "Work packages" in Takt planning are identical, although Takt literature has used one formula and LBMS two formulas to achieve the same result (Table 1). However, LBMS extends these calculations by explicitly deriving schedule dates, float values, and the critical path for each task across locations. Such location-specific schedule calculations have not been formally described in the existing Takt planning literature.

Despite the shared duration logic at the work-content level, the two methods differ fundamentally in their treatment of buffering and higher-level coordination. In Takt planning, capacity buffers are incorporated as utilization constraints at the wagon level, whereas LBMS applies time buffers through logical relationships between tasks, conceptually similar to lags in critical path method (CPM) scheduling. In addition, the concept of a train represents a higher aggregation level that is specific to Takt planning and has no direct counterpart in LBMS.

The different calculation approaches across planning levels are summarized in Table 1, while all parameters used in the formulations are listed in Appendix A.1. The implications of these technical differences are illustrated and discussed in the following section using a practical case study.

Table 1: Comparison of the calculation approaches in LBMS and Takt planning on different levels.

	LBMS	Takt planning
Level	**Task in Location**	**Work package**
	$h^T_j = \sum_{i=1}^{i=n} (Q_{i,j} \times R^C_{i,j})$ $D_{i,j} = \frac{h^T_j}{8 \left[\frac{h}{d}\right] \times C}$	$D_x = \frac{V_x \times R^C}{8 \left[\frac{h}{d}\right] \times C}$
Level	**Task in a schedule**	
	1. CPM Forward Pass $ES_{i,j} = max(EF_{predecessor\ of\ i\ +\ TB})$ $EF_{i,j} = ES_{i,j} + D_{i,j}$ 2. LBMS Heuristic $ES_{i,j} = EF_{i,j-1}$ *by delaying early locations* 3. Task Duration $D_{i,total} = \sum_{j=1}^{n} D_{i,j}$	
Level		**Wagon**
		$W_x \hat{=} TT$ $W_x: 0,8 \leqq \frac{D_x}{TT} = CU_x \leqq 0,95$

Level	Train
	$T_x = W_{x1} + W_{x2} \ldots$ $T_{x,TT} = \frac{W_{x,\ overall}}{TT} = 0{,}8 \leqq CU_x \leqq 0{,}95$

Simplified comparative analysis

A simplified comparative analysis was conducted as an initial step to isolate and illustrate the core methodological differences between the Location-Based Management System (LBMS) and Takt planning under controlled conditions. The analysis focused on two representative interior construction processes "Drywall" and "Screed" executed sequentially across three locations.

The simplified example is not intended to represent a realistic construction project. Instead, it serves to develop analytically grounded expectations regarding the effects of variable work densities, buffering concepts, and resource continuity inherent to both methods. To maintain clarity in the main text, detailed input parameters, calculation assumptions, and a structured comparative table of the two planning approaches are provided in Appendix A.2.

Using Location-based management approach

To calculate the work hours for the tasks "Drywall" and "Screed" using the LBMS in the project, the BoQ items and their respective scopes within each location were identified. Subsequently, the "Task in Location"- formula was applied to compute the work hours for "Drywall" and "Screed" in each location (Fig. 1). Flow line visualization reveals slope variations corresponding to location-specific work hours. Because the task "Screed" is faster than "Drywall", the start dates of early locations of "Screed" have been pulled by the continuity heuristics from LBMS (Fig. 2). The delayed start times prevent discontinuous work between locations. However, the downside of this continuous flow is the large gap between the "Drywall" and "Screed" tasks when using a single crew (Fig. 2).

LBMS proceeds by attempting to eliminate the empty space by aligning the slopes through adjusting manpower. Three drywall workers and two screed workers result in closely aligned total durations for both tasks (Fig. 3). With these resources, both tasks have the same total duration of 21 days. This brings the tasks closer together and eliminates the empty space (Fig. 4). It should be noted that due to quantity differences between locations, the empty space between tasks differs by location. Finally, a time buffer TB of three days is added between the tasks to protect the continuous flow, which results in a three-day increase in project duration (Fig. 4).

Location	CW = 40h (5 days/ 8h)			
	Process	h^T_j	Crew Size	Duration
A	Drywall	110 h	1	14 d
	Screed	68 h	1	9 d
B	Drywall	144 h	1	18 d
	Screed	111 h	1	14 d
C	Drywall	252 h	1	31 d
	Screed	166 h	1	21 d

Figure 1. LBMS "Task in Location" calculation: Level formula with single crew application.

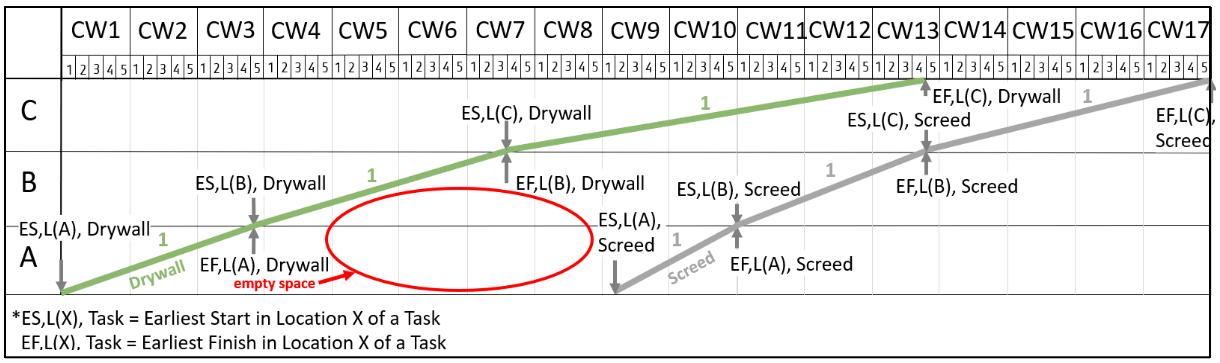

Figure 2. Flow line illustration following "Task in Location" level formula calculation with single crew deployment.

Location	CW = 40h (5 days/ 8h)			
	Process	h^T_j	Crew Size	Duration
A	Drywall	110 h	3	3 d
	Screed	68 h	2	9 d
B	Drywall	144 h	5	4 d
	Screed	111 h	2	7 d
C	Drywall	252 h	5	6 d
	Screed	166 h	2	10 d

Figure 3. Optimized LBMS calculation approach for "Drywall" and "Screed" tasks.

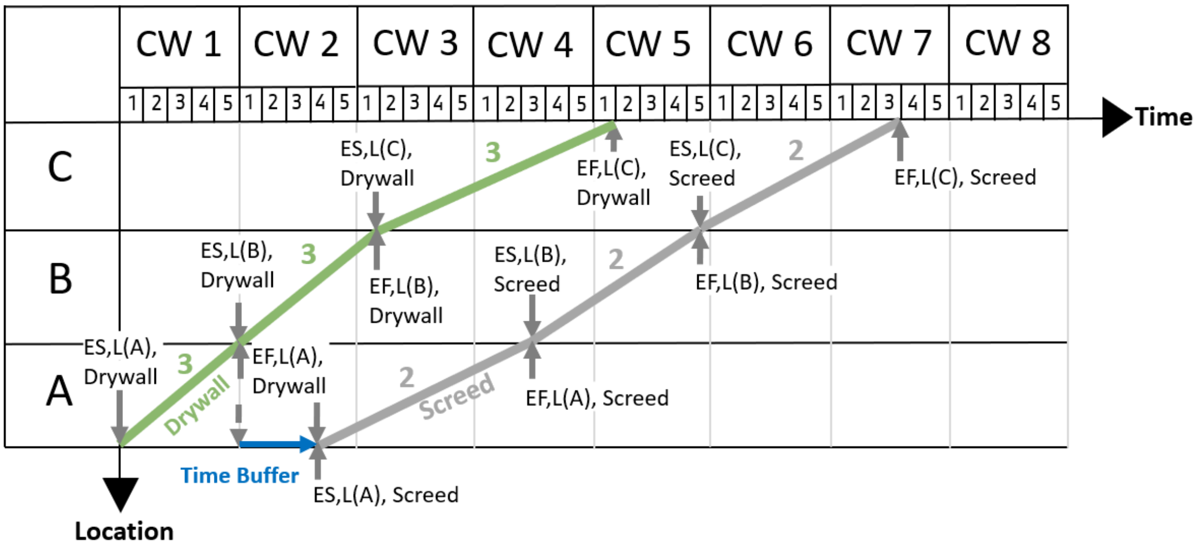

Figure 4. Flow line illustration after "Task in schedule" level calculation with LBMS continuity heuristics and integrated time buffer.

Using Takt calculation approach

There are two ways to start a Takt approach for this example: top-down and bottom-up. The top-down approach starts with an overall project duration and derives takt times and work sequences at a higher aggregation level, whereas the bottom-up approach begins at the work package level. Bottom-up is more comparable to LBMS, so it is used for this example. It starts at the "Work package" level formula (Tab. 1), grouping tasks into work packages and then assembling them to form a wagon (Dlouhy et al., 2016; Binninger et al., 2017).

The total duration of the individual work steps is calculated. The work steps are aggregated into work packages. In Takt planning, the "Work package" level formula includes the crew size in the calculation and is identical to the "Task-in-Location"-level formula of LBMS. Work packages are then allocated to wagons. These work packages denoted as D_x are divided within a specified takt time TT_x. Wagon level constraint requires an 80-95% capacity utilization:

$$W_x: 0{,}8 \leqq \frac{D_x}{TT} = CU_x \leqq 0{,}95$$

In this example, a weekly takt time of 40 hours has been set. Drywall and Screed work packages have been allocated into their respective wagons. Resources are selected separately for each work package so that the duration is below the takt time. Drywall wagon in location C has more than 40 hours, while Screed wagon has consistently less than 80% of takt time (Fig. 5), so initially the constraint is not satisfied. "Drywall" can be adjusted to fit the takt time by splitting some part of the scope into separate work packages: "Drywall 1" and "Drywall 2". WP "Drywall 1" is done within the Drywall wagon, while "Drywall 2" is combined with WP "Screed" in the Screed wagon (Fig. 6). This arrangement ensures the workload of both trades fulfills the takt time including capacity buffers. The wagons form a train, which moves through A,B and C in trade sequence (Fig. 7). Each Takt area contains different work densities, creating varying workloads across work packages. The utilization of wagons is between 80% and 95% in all locations and a consistent takt time of 40 hours can be achieved with recommended capacity buffer size between 5-20%.

Takt area	CW 1 CW = 40h (5 days/ 8h)					CW 2 CW = 40h (5 days/ 8h)				
		Process	Crew Size	D_x	CU_x		Process	Crew Size	D_x	CU_x
A	Wagon	Drywall	3	38h	0,95	Wagon	Screed	3	25h	0,62
B	Wagon	Drywall	4	36h	0,9	Wagon	Screed	5	22h	0,55
C	Wagon	Drywall	6	43h	1,08	Wagon	Screed	6	28h	0,7

"Wagon"-level formula not achieved.

Figure 5. Work packages do not fulfil the requirements for the wagon (Takt time, TTx= 40h).

Takt area	CW 1 CW = 40h (5 days/ 8h)					CW 2 CW = 40h (5 days/ 8h)				
		Process	Crew Size	D_x	CU_x		Process	Crew Size	D_x	CU_x
A	Wagon	Drywall 1	3	32h	0,8	Wagon	Drywall 2	2	13h	0,95
							Screed	3	25h	
B	Wagon	Drywall 1	3	37h	0,93	Wagon	Drywall 2	3	10h	0,8
							Screed	5	22h	
C	Wagon	Drywall 1	6	33h	0,83	Wagon	Drywall 2	6	10h	0,85
							Screed	7	24h	

Splitting work package to balance wagon with capacity buffer.

Figure 6. The drywall work packages are split into two and the latter part is allocated to Screed wagon. 5% capacity buffer included (Takt time, TTx= 40h).

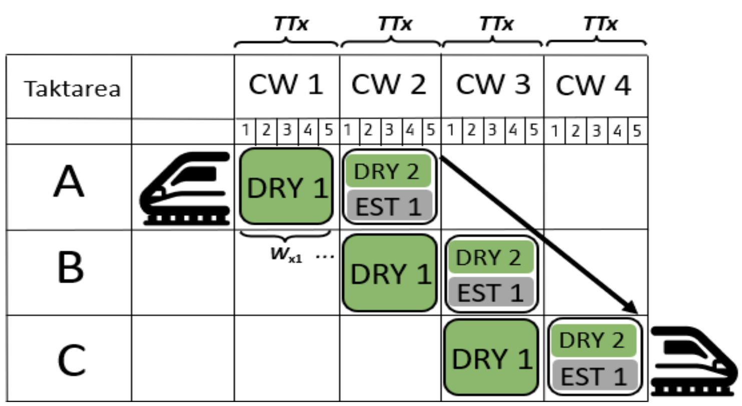

Figure 7. Example of a train based on Wagons Wx with the segmented work packages Dx (Takt time, TT_x= 40h).

Comparison of the resources and flow

The calculation examples show that the starting data of methods are identical. Both methods start from calculating the total work hours by location. Differences emerge in resource calculations and optimization methods.

As default assumption, LBMS assigns constant resources in all locations. It is a planning decision to change resources for each location. This makes the resource graph by default level (Fig. 8). Takt planning adjusts the resource individually for each work package according to the work hours of the takt area. Each wagon can contain multiple work packages whose resources are individually adjusted. For example, Takt area C, with a higher work volume, was planned for a higher number of workers. This results in a fluctuation of manpower in Takt (Fig. 8). If locations have variable quantities, LBMS achieves more balanced resource use while Takt planning has more changes in manpower.

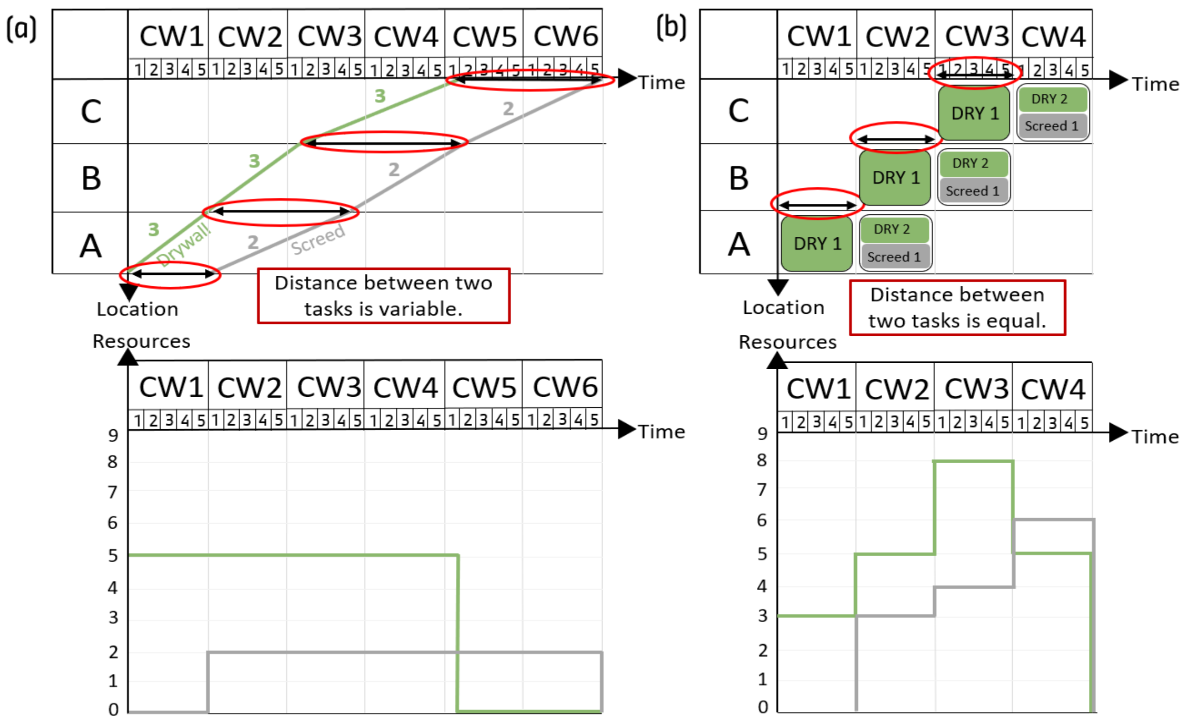

Figure 8. Comparison of the interactions between flow and resources in LBMS (a) and Takt (b).

Both LBMS and Takt planning method aim to establish a steady pace of work to optimise the use of labor and materials on construction projects. To achieve continuous resource flow, LBMS sacrifices continuous process flow. Even though LBMS schedule is calculated with 100% utilization (no capacity buffers), it has a longer duration than the Takt schedule because it uses time buffers and the distance between the tasks is variable. Variable distances are caused by keeping resources constant and allowing durations to vary when work volumes are different (Fig. 8). In contrast, Takt planning uses a fixed takt time to maintain equal intervals between processes. The fixed takt time enables an optimized process flow but neglects trade flow (Fig. 8). If location sizes are variable, LBMS achieves better trade flow, while Takt planning achieves better process flow which enables shorter durations.

Case study

To validate the assumptions and findings derived from the simplified comparative analysis in a more realistic project context, a comprehensive construction sequence from a real project was examined. The project has been used since 2006 by academics in LBMS teaching but the data were initially collected from a real medical office building project in California. The LBMS model answer is known which makes it a good comparison for this analysis. The starting data includes quantity information, resource consumption rates and maximum resource availability for each contractor and logic links between work packages. All input parameters are documented in Appendix A.3. The case study investigates how the differing planning logics of LBMS and Takt planning manifest in a real construction project characterized by heterogeneous location sizes and increased process complexity. The Location Breakdown Structure of the project has large locations, but they were not modified for this case study.

Schedules were planned using LBMS and Takt planning approaches. The results are shown in flowline and takt formats in Figure 9. In the Takt representation (lower part of figure), the process follows a regular and repetitive pattern. Several processes take multiple takt times due to resource constraints in the starting data. The LBMS approach (top part of figure) emphasizes straight, continuous lines without resource changes between locations. In the Takt planning approach, idle wagons are mostly successfully eliminated. This results in a reduction of the overall construction duration by three weeks.

In contrast, the LBMS-based schedule shows visible gaps between successive processes. Faster processes have been split and they are performed in several stages which include fast work through several locations (shown as close to vertical lines in middle of the project). Some of the gaps naturally emerge due to different production rates of consecutive trades. Others are planned time buffers. To make the methods comparable, the total capacity buffer in the tightest location was calculated in the takt schedule, and the same number of days was added to LBMS as time buffers. As a result, the overall project duration in the LBMS scenario is extended by three weeks compared to the Takt-based schedule, exactly achieving the project deadline.

Figure 9. Comparison of project sequence in LBMS (above) and Takt planning (below).

The weekly mobilized workforce over the project duration for the Takt and LBMS planning approaches is calculated for each week (Fig. 10). The horizontal axis represents the project timeline in calendar weeks, while the vertical axis shows the number of mobilized workers per week. For both methods, the temporal workforce profiles as well as their respective average workforce levels are depicted.

The results reveal distinct differences in workforce dynamics between the two planning approaches. The Takt-based schedule exhibits higher variability in workforce demand. Following a gradual ramp-up phase at the beginning of the project, the number of mobilized workers increases continuously and reaches a distinct peak in the middle phase of the project. This peak substantially exceeds the average workforce level of the Takt approach, indicating periods of intensified parallel production across multiple takt areas. After reaching the maximum, workforce demand declines steadily toward project completion, resulting in a symmetrical upturn–downturn pattern over the overall duration.

In contrast, the LBMS-based schedule shows a comparatively smoother workforce profile. Although moderate fluctuations are present, the weekly number of mobilized workers remains closer to the LBMS average of 24 over most of the project duration. Peaks are less pronounced and shorter in duration, indicating a more level allocation of labor resources. This behavior reflects the LBMS planning logic, which prioritizes continuity of crews across locations and allows task durations to adjust in response to varying work densities.

A comparison of the average workforce levels further highlights the trade-off between both approaches. While the Takt method achieves shorter overall project duration by eliminating time buffers, this comes at the cost of a higher average workforce requirement and increased short-term workforce peaks. LBMS uses fewer mobilized workers and lowers peak demand, but extends the total project timeline. It should be noted that takt capacity buffers consume resources while time buffers are not reflected in the graph because they are empty space between tasks.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Takt	8	14	14	18	18	20	20	22	25	28	31	32	34	35	38	38	38	40	44	48	49	50	54	53	60	59	51	52	54	50	59
LBMS	4	14	14	14	14	18	18	18	18	21	22	22	25	33	33	38	36	38	38	26	26	26	26	22	22	19	29	29	30	30	27

Week	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Takt	54	52	57	54	47	50	50	55	58	42	50	46	36	36	28	29	27	29	20	20	16	11	11	5	5	5	3	0	0	0	0
LBMS	19	19	20	15	15	24	33	33	36	37	39	34	35	46	40	40	40	32	32	33	23	23	24	23	17	17	17	17	5	4	0

Figure 10. Presentation of workforce over the project period per week and average value.

Figure 11 illustrates the weekly workforce profile for the trade "Drywall" under the Takt- and LBMS-based schedules and highlights how different coordination logics affect trade-level resource stability. In the Takt scenario, workforce demand shows stronger week-to-week variability with higher peaks, reflecting the adjustment of crew sizes to meet fixed takt-time constraints. In the LBMS scenario, workforce demand is more even over time, consistent with the method's emphasis on continuous crew deployment and reduced mobilization and demobilization events.

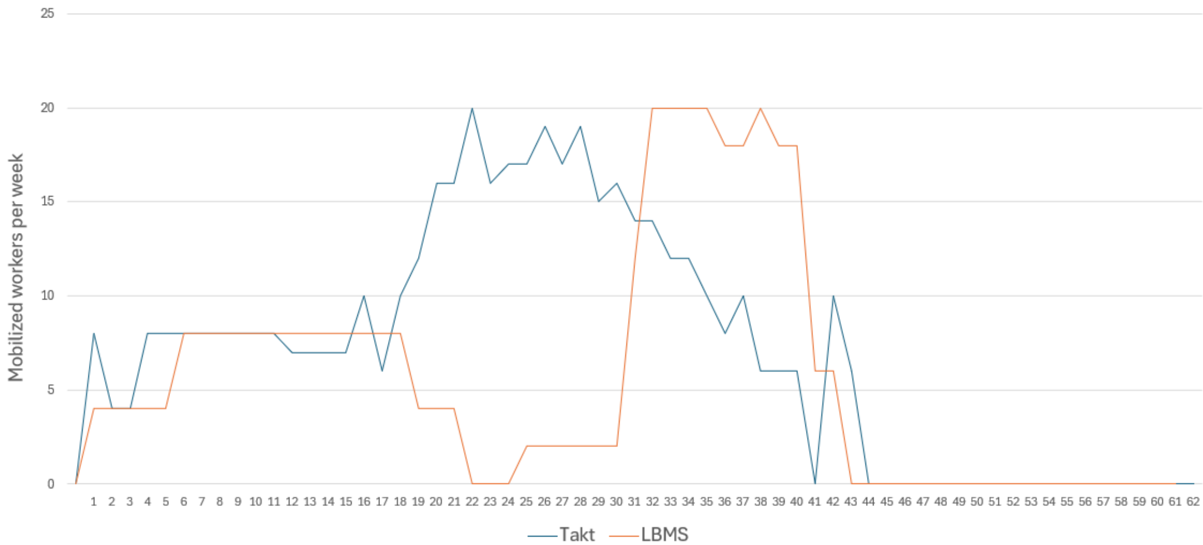

Figure 11. Presentation of workforce for the subcontractor "Drywall" over the project period per week and average value.

Table 2 summarizes subcontractor-level workforce indicators (total resource use, peak resource use, and the number of mobilization/demobilization events) for both approaches. The comparison shows that Takt planning tends to increase mobilization and demobilization dynamics for several trades due to area-specific crew adjustments, whereas LBMS generally results in fewer crew changes and a more stable deployment pattern. The total resource use of takt is larger than LBMS because of the different buffering mechanism.

Table 2. Workforce utilization by subcontractor.

Subcontractor		Takt	LBMS
Drywall	Total resource use	448	344
	Peak resource use	20	20
	Number of mobilization and demobilization	25	12
Fireproofing	Total resource use	214	200
	Peak resource use	10	10
	Number of mobilization and demobilization	3	2
Fire Sprinkler	Total resource use	48	36
	Peak resource use	2	3
	Number of mobilization and demobilization	2	2
Ceiling	Total resource use	180	148
	Peak resource use	12	12
	Number of mobilization and demobilization	10	3

Subcontractor		Takt	LBMS
Electrical	Total resource use	229	241
	Peak resource use	11	11
	Number of mobilization and demobilization	30	4
Casework	Total resource use	138	100
	Peak resource use	12	10
	Number of mobilization and demobilization	6	1
Mechanical	Total resource use	351	136
	Peak resource use	15	12
	Number of mobilization and demobilization	35	10
Plumbing	Total resource use	96	79
	Peak resource use	5	7
	Number of mobilization and demobilization	23	4
Painting	Total resource use	86	84
	Peak resource use	7	6
	Number of mobilization and demobilization	6	2
Specialities	Total resource use	19	6
	Peak resource use	1	1
	Number of mobilization and demobilization	2	2
Floor Coverings	Total resource use	180	144
	Peak resource use	12	12
	Number of mobilization and demobilization	5	2
Doors, Frames and Hardware	Total resource use	64	24
	Peak resource use	4	4
	Number of mobilization and demobilization	13	2

Results

To provide a quantitative comparison of LBMS and Takt planning, Table 1 summarizes the key project-level differences in duration and workforce metrics derived from the case study. Both planning approaches are based on identical total workload of 63 042 person hours, ensuring that observed differences result exclusively from coordination logic, buffering strategies, and resource allocation.

Table 3 summarizes the key quantitative differences between the LBMS-based and Takt-based schedules derived from the case study. Both approaches are based on an identical total workload of 63 042 work hours, ensuring a method-neutral comparison. Differences in project performance therefore result exclusively from coordination logic, buffering strategies, and resource allocation. As noted before, capacity buffers inflate the theoretical takt resource use in this comparison. If time buffers had to be used in LBMS due to delays, its resource use would also expand.

The Takt schedule reduced the project duration to 58 weeks, compared to 61 weeks for the optimized LBMS schedule (Δ = −3 weeks, ≈ 5%). This reduction is accompanied by a higher average weekly workforce (35 vs. 24 workers/week) and higher total labor input (2052 vs. 1542 worker-weeks). Workforce variability, calculated from weekly mobilized workforce values over active project weeks, is higher under Takt planning (Std. dev. = 17.1, CV = 0.48) than under LBMS (Std. dev. = 9.6, CV = 0.38), reflecting the ramp-up phase and mid-project peak observed in the case study (Fig. 9 and 10).

The following sections explain these results by linking them to the shared calculation logic and the differing approaches to buffering, work bundling, and resource-time coordination.

Table 3: Quantitative comparison of project duration and workforce metrics for LBMS and Takt planning.

	LBMS	Takt planning	Δ
Project duration (weeks)	61	58	**- 3**
Work hours in h (Total)	63 042	63 042	=
Average weekly workforce (workers/weeks)	24	35	+ 11
Total labor input (Sum weekly workforce)	1542	2052	+ 510
Peak workforce (max workers/week)	46	60	+ 14
Workforce variability (Standard deviation, workers/week)*	9.6	17.1	+ 7.5
Workforce variability (CV)*	0.38	0.48	+ 0.10

*Workforce variability is reported as the sample standard deviation and coefficient of variation (CV = std./mean), computed from weekly mobilized workforce over active project weeks only (workforce > 0)(Appendix A.4.).

Similarity 1: Duration calculation on „Work package"- Level and „Task in Location"- Level

The principal technical similarity between LBMS and Takt planning lies in their identical duration calculation logic at the "Work package" and "Task in Location" levels (Tab. 1). In both methods, BoQ items or work steps are identified per location and aggregated into executable units. Total work hours serve as the common measure of work density. Consequently, both approaches rely on the same computational basis for duration formation. Differences in project outcomes therefore do not stem from the underlying workload or calculation method.

Similarity 2: Concept of Wagon and Task

Both methods also use higher-level planning units to structure workflow. LBMS aggregates BoQ items into tasks. Takt planning first groups work steps into work packages and then combines them into wagons. In both cases, these units are used to coordinate continuous flow across all project areas (Fig. 8). Buffers are defined at this level in both methods. LBMS applies explicit time buffers between successive tasks to protect workflow continuity. Takt planning embeds capacity buffers by enforcing utilization constraints at wagon level (Tab. 1).

Difference 1: Fixed vs. variable durations

The LBMS permits task durations to vary in response to differences in work density across locations. This leads to variable temporal distances between tasks (Fig. 8). In the case study, LBMS was actively optimized by adjusting crew size to align task slopes and maintain continuous trade flow. Remaining variability was addressed through the introduction of time buffers between tasks to protect successor activities (Fig. 4). These buffers manifest as visible gaps between tasks and extend the overall project duration (Fig. 9).

Takt planning follows a different logic. A fixed takt time enforces equal time intervals between processes (Fig. 8). Empty spaces between wagons occur only if buffer wagons are planned explicitly or if work content is missing in certain areas. This minimized idle wagons and produced a more compact schedule. Compared to the optimized LBMS schedule, this resulted in a reduction of three weeks in total project duration (Fig. 9).

Difference 2: Splitting and combining work

In Takt planning, a wagon may contain work packages from multiple trades (Fig. 6). When workload inconsistencies arise, work packages can be split and reassigned across wagons to maintain the takt time while respecting capacity buffer constraints (Fig. 6). Resources are planned at the work-package level. This allows flexible recombination of work within the takt structure

LBMS does not distinguish work packages as a separate planning entity. BoQ items of the same trade can be shifted between tasks. However, each task typically represents the scope of a single contractor. This limits cross-trade bundling but supports continuous deployment of trade-specific crews.

Difference 3: Resource – Time Allocation

LBMS prioritizes stable resource utilization and accepts variable task durations to accommodate differences in work density (Fig. 8). Continuous tasks have a more balanced resource use. In the case study, this resulted in relatively even resource utilization (Fig. 10).

At subcontractor level, this stability is also reflected in fewer mobilization and demobilization events and lower total resource use for several trades (Tab. 2), as illustrated for the Drywall subcontractor in Figure 11. However, variable task spacing and time buffers increased the overall project duration. The LBMS schedule was optimized with respect to resource continuity rather than time compression.

Takt planning adapts resource levels to ensure that area-specific workloads fit within the fixed takt time. This results in shorter durations and improved process flow. The workforce profile in the case study shows a distinct ramp-up phase at the beginning of the project, followed by a pronounced peak in the middle of the construction period (Fig. 10). This peak is caused by intensified parallel production across multiple areas. At subcontractor level, the same logic leads to more frequent crew adjustments and higher mobilization dynamics in several trades (Tab. 2) and to stronger week-to-week variability for the Drywall subcontractor (Fig. 11). As a result, average resource utilization is higher, but workforce demand fluctuates more strongly over time.

In summary, LBMS and Takt planning use identical duration calculations but differ fundamentally in how buffers and resources are applied. LBMS emphasizes trade continuity and resource stability through variable durations and time buffers. Takt planning enforces fixed temporal rhythms by adapting resources to a constant takt. Even without splitting the large locations to enable shorter takt times, the Takt approach achieved a shorter construction duration in the case study than the optimized LBMS schedule. This highlights the impact of the underlying planning logic.

Discussion

This study provides a technical comparison of LBMS and Takt planning approaches that extends previous conceptual comparisons by explicitly linking calculation logic, buffering strategies, and resource–time coordination to quantitative project outcomes. Earlier studies discussed differences in flow orientation and control principles (Seppänen, 2014; Frandson et al., 2015) but did not explain *why* these differences translate into shorter durations or more stable resource profiles. The main contribution of this research is to demonstrate that the duration–resource trade-off observed between LBMS and Takt planning is structurally embedded in their distinct buffering and coordination logics rather than differences in workload calculation. While both approaches rely on identical location-level duration calculations, they differ substantially in (i) how work is bundled, (ii) how buffers are implemented, and (iii) how time and resources are coordinated.

The following sections discuss these differences in detail. First, the discussion explains why Takt planning achieves shorter project durations at the cost of resource continuity. It then shows that location-level calculations are technically identical in both methods, before analyzing differences in work bundling and buffering as the key mechanisms driving the observed performance trade-offs.

Takt schedules achieve shorter durations but sacrifice resource continuity

Consistent with prior comparative studies, the case study confirms that Takt planning achieves shorter overall duration while LBMS yields a more stable workforce profile (Frandson et al., 2015; Seppänen, 2014). In the quantitative results the Takt schedule reduced project duration to 58 weeks compared to 61 weeks under the optimized LBMS schedule (Δ = −3 weeks, ~5%). At the same time, this study extends prior work by explaining *why* this trade-off occurs. The results indicate that the shorter duration in Takt planning is linked to the enforcement of fixed time. In the case study, the Takt schedule shows tighter sequencing with fewer idle spaces, whereas LBMS displays gaps between tasks that function as time buffers and lengthen the overall construction time.

The workforce profiles further reinforce this mechanism. In line with earlier observations that Takt systems can increase parallel production, the case study shows a distinct ramp-up phase and a pronounced mid-project peak in workforce demand under Takt planning. This peak reflects intensified parallel execution across multiple areas. By contrast, the LBMS schedule exhibits a smoother workforce profile and remains closer to its average workforce level over most project weeks.

In this case study, the original starting data was collected for LBMS. If takt areas and times had been additionally optimized for takt by dividing the areas into smaller areas, the duration advantage of takt would increase through increased parallel work of activities. This was not done because the dataset did not include more granular quantity information. Even with more detailed location breakdown, the resource advantage of LBMS would remain the same.

Location Level calculations are identical

Location-level duration calculations are technically identical in LBMS and Takt planning. Both approaches form durations from work hours as the common measure of work density by aggregating BoQ items (LBMS) or work steps (Takt) into executable units. This confirms that differences in project outcomes are not caused by different workload estimation rules, but by higher-level planning choices.

This finding strengthens earlier conceptual comparisons by providing an explicit equation-level explanation. It also has practical implications: since both methods rely on the same workhour-based core, software environments could support both LBMS and Takt planning using shared calculations while allowing different scheduling options through buffer logic and takt-time constraints.

Differences in bundling work

Prior studies have noted that both methods can shift scope between planning units (tasks or wagons) to balance workflow (e.g., Frandson et al., 2015). This study adds a sharper technical distinction: Takt planning separates *work packages* from *wagons* and assigns resources at the work-package level (Binninger et al., 2016), whereas LBMS assigns resources at the *task* level (Kenley & Seppänen, 2010) and does not treat work packages as an explicit entity.

This difference matters because it changes the feasible set of coordination decisions. Takt allows work packages to be split and recombined across wagons (including cross-trade bundling when feasible), which supports maintaining takt time even under uneven workloads (Dlouhy et al., 2016; Dlouhy, 2022). LBMS supports continuous flow of trades but limits cross-trade bundling. Continuity is protected by pulling start dates of early tasks which often leads to gaps in the project schedule. This approach supports stable trade continuity but reduces opportunities for time compression when work densities vary.

Thus, the case study observations are consistent with the qualitative claims in earlier work (trade continuity vs. process flow), but this paper clarifies the technical mechanism behind that distinction by showing how the bundling hierarchy constrains (LBMS) or enables (Takt) recombination and sequencing decisions.

Differences in buffering

The buffer distinction reported in earlier research (capacity buffers in Takt vs. time buffers in LBMS (e.g., Frandson et al., 2015) is confirmed and made more explicit through technical comparison and the case study. In Takt planning, buffering is embedded through utilization constraints at wagon level. Wagons are intentionally underloaded, typically targeting approximately 80–95% utilization, which creates capacity buffers within each takt interval of 5-20%. Because resources are reserved for the capacity buffer, takt schedules have higher average resource use than LBMS schedule.

In LBMS, buffering is implemented primarily as explicit time buffers between tasks and as emergent gaps when task spacing varies across locations due to differing production speeds and quantities. These buffers protect against cascading delays and stabilize trade continuity, but they also increase the total duration by adding empty space in the schedule. Because there are allowances for delay between tasks, they do not reserve resources unless needed, resulting in lower average resource use.

The case study supports the practical consequences of these buffering logics. Capacity buffers and fixed takt times enable tighter schedules but increase workforce variability (as seen in the ramp-up and mid-project peak) and theoretical resource use. When capacity buffers are included in the schedule, they are often used to perform “off-takt” activities when they are not needed or include preparatory time for next takts. Time buffers stabilize resource use but extend the schedule, consistent with the longer duration and smoother workforce profile with a low mobilization and demobilization rate under LBMS. It should be noted that with time buffers, only the theoretical resource use is lower. However, during construction, any delays that use the time buffer will lead to increased resource use. In future research, simulation studies should be conducted to further study the resource profiles under variability.

Practical contributions

Practitioners should select the scheduling method based on project-specific conditions rather than assuming universal superiority of either approach. When stable resource deployment is critical and workforce fluctuations pose operational or contractual risks, LBMS represents a robust option, particularly if overall project duration is not the primary constraint. By contrast, when sufficient resource flexibility exists e.g. through partnering agreements with trade contractors, Takt planning can be leveraged to achieve meaningful reductions in project duration.

The findings of the case study indicate that capacity buffers combined with a consistent takt time enable shorter schedules by eliminating idle spaces and maintaining equal time intervals between processes. This benefit, however, comes at the cost of increased workforce variability when work densities differ across locations, as crew sizes must be adjusted to respect capacity utilization limits. LBMS follows the opposite logic: by maintaining stable crews and allowing task intervals to vary, it achieves more balanced resource usage but requires time buffers that extend the overall project duration.

To support decision-making in selecting the appropriate scheduling approach, a decision tree is presented in Figure 12. The decision tree synthesizes the analytical findings of this study and guides practitioners through key project characteristics such as resource flexibility, variation in work amounts between locations, and the desired buffering logic.

If work quantities (work density) do not vary significantly across locations, both methods tend to lead to similar outcomes because there is little need for rebalancing. In this case, practitioners may prefer *Takt* because the fixed takt rhythm is typically easier to communicate and understand on site.

The left branch of the tree should be read as a prioritization question rather than as a choice of whether to have a buffering strategy: both approaches include buffering as part of their production system (capacity buffers in Takt; time buffers in LBMS). The decision therefore depends on the dominant project objective, i.e., whether the project primarily aims to minimize total duration by enforcing a constant rhythm (Takt planning) or to achieve an even, continuous resource utilization with stable crews (LBMS).

Overall, Figure 12 should be understood as a planning-phase decision aid that supports method selection based on structural project characteristics and intended buffering logic.

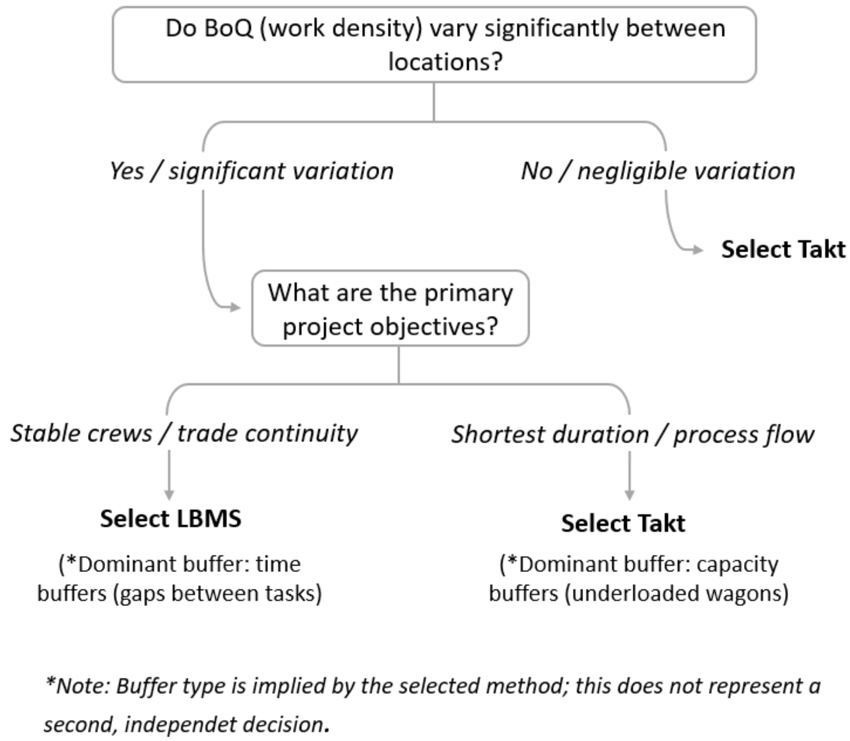

Figure 12. Decision tree to support the selection of the appropriate scheduling approach.

Limitations and Future Research

One limitation of this study is that the analysis is based on a simplified comparative setup involving two consecutive trades, followed by the examination of a single interior construction sequence applying both LBMS and Takt planning. As only one project sequence was analyzed, the observed effects could not be validated across multiple projects. Consequently, the generalizability and robustness of the findings remain limited.

Furthermore, the scope of this work is restricted to the planning phase of both methods. Additional differences and challenges are expected to emerge when considering controlling and operational management aspects during project execution. In particular, the interaction between planned buffers, control actions, and actual production performance was not addressed in this study.

In addition, the decision tree is derived from a planning-phase comparison and does not explicitly capture execution-phase control (e.g., production control routines) or the effects of variability and delay propagation across locations and trades. Extending the decision logic with controlling-related criteria and variability-sensitive performance measures is a promising direction for future research.

Future research should therefore extend the analysis to multiple projects with varying characteristics to validate the findings across different contexts. Modelling several complete projects with realistic quantities, higher process complexity, and multiple interacting trades would allow a more comprehensive assessment of how time and capacity buffers influence overall project duration and resource behavior.

In addition, the controlling approaches of LBMS and Takt planning warrant detailed empirical comparison. Investigating how both methods perform during execution -using production control metrics such as Percent Plan Complete (PPC), constraint removal efficiency, or delay propagation -would provide deeper insight into their practical implications beyond planning.

Finally, while this study focused exclusively on planning methodologies, the development of hybrid planning guidelines, integrated control concepts, and actionable dashboards was considered beyond its scope. These areas represent promising directions for future research aimed at improving practical applicability.

Conclusion

This study contributes to a deeper technical understanding of construction planning methodologies by comparing LBMS and Takt planning through a detailed practical case. While both methods aim to achieve aligned and continuous workflows, they differ fundamentally in their core planning logic and operational emphasis. The analysis confirms earlier research while providing new, quantitatively grounded insights into the trade-off between project duration reduction and resource levelness.

The findings show that Takt planning can achieve shorter project durations when capacity buffers are combined with a consistent takt time, enabling tighter process sequencing and reduced idle space. However, this benefit is accompanied by increased workforce variability when work quantities differ across locations, as resources must be adjusted to satisfy capacity constraints. LBMS follows the opposite logic: by prioritizing trade continuity and stable crew deployment, it achieves more balanced resource utilization but accepts longer project durations due to variable task spacing and the use of time buffers.

Importantly, the study demonstrates that these performance differences are not driven by discrepancies in workload calculation. Under uniform work densities, both methods can yield comparable results, even without buffering. Moreover, key drawbacks of Takt planning can be mitigated when quantity variations are sufficiently small to be absorbed by capacity buffers without changing crew sizes.

These results emphasize that method selection should be guided by project-specific characteristics, particularly work-density variation and resource flexibility. They also highlight the potential value of hybrid or adaptive planning approaches that combine the strengths of LBMS and Takt planning. Overall, this research lays a foundation for future work on buffer optimization, resource efficiency, and integrated planning concepts, while supporting more informed decision-making for both practitioners and researchers through a transparent explanation of the underlying technical mechanisms.

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Appendix A.1 Overview of parameters and notion

This appendix summarizes all parameters and symbols used in the mathematical formulations of LBMS and Takt planning to ensure consistency and replicability.

Parameter	Meaning	Unit
$h^T{}_j$	Total hours for the location *j*.	h [hours]
$Q_{j,j}$	The quantity for item *i*, in location *j*.	m^2
$R^C{}_{i,j}$	The labor consumption rate for item I, in location j and where n items being grouped into a single task i.	h/m^2 [hour per square metre]
$8\left[\frac{h}{d}\right]$	Eight work hours per day.	$8\left[\frac{h}{d}\right]$
C	Crew size	Amount of worker
$ES_{i,j}$	Earliest time at which a task *i* can begin at location *j*.	Date/time or days/hours (relative time since project start)
TB	Time Buffer	d [days]
$EF_{i,j}$	Earliest time at which task *i* can be completed at location *j*.	Date/time or days/hours (relative time since project start)
$D_{i,j}$	Duration of task *i* in location *j*. Describes the time required to complete task *i* at location *j*.	d [days]
$D_{i,total}$	Total duration of a task *i* over all locations within a project with a constant crew size.	d [days]
T_x	Takt train	TT [Takt time]
TT	Takt Time of production system	d [days] *or* h [hours]
W_x	Wagon duration*[in TT]*	TT [Takt time]
$W_{x,\ overall}$	Duration of all Wagons of a Train	TT [Takt time]
$T_{x,TT}$	Duration of a Takt train including capacity buffer.	TT [Takt time]
CU_x	Capacity utilisation (~80-95%)	%
D_x	Average duration of work package x	d [days] *or* h [hours]
V_x	Volume of work of work package x	Unit of measurement for work [m^2, m^3, m, l, count]
R^C	Labor consumption rate	h/m^2 [hour per square metre]
p_x	production rate	units per time unit

Appendix A.2. Calculation simplified Example 'Drywall' and 'Screed' for LBMS

This appendix provides a structured overview of the calculation logic at different planning levels, highlighting where the methods share identical formulations and where they diverge conceptually.

Location	CW = 40h (5 days á 8h)	CW = 40h (5 days á 8h)

A

Drywall					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Separating strips	50 m²	0,12 h/m²	6 h	1	1 d
Closing shafts	25 m²	0,35 h/m²	9 h	1	1 d
Insulating drywall	100 m²	0,05 h/m²	5 h	1	1 d
Planking 2nd side	100 m²	0,045 h/m²	45 h	1	6 d
Applying first layer	100 m²	0,2 h/m²	20 h	1	3 d
Filling Q3-Quality	100 m²	0,2 h/m²	20 h	1	3 d
Sanding drywalls	100 m²	0,05 h/m²	5 h	1	1 d
			110 h		14 d

Screed					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Cleaning the surface	25 m²	0,48 h/m²	12 h	1	2 d
Laying backfill	25 m²	0,76 h/m²	19 h	1	2 d
Sound insulation	25 m²	0,76 h/m²	19 h	1	2 d
Edge insulation strips	10 m	0,38 h/m	4 h	1	0 d
Seperating foil	25 m²	0,58 h/m²	15 h	1	2 d
			68 h		9 d

$$h^T_j = \sum_{i=1}^{i=n} (Q_{i,j} \times R^C_{i,j})$$

$$D_{i,j} = \frac{h^T_j}{8 \left[\frac{h}{d}\right] \times C}$$

B

Drywall					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Separating strips	20 m²	0,12 h/m²	2 h	1	0 d
Closing shafts	25 m²	0,35 h/m²	9 h	1	1 d
Insulating drywall	150 m²	0,05 h/m²	8 h	1	1 d
Planking 2nd side	150 m²	0,045 h/m²	68 h	1	8 d
Applying first layer	100 m²	0,2 h/m²	20 h	1	3 d
Filling Q3-Quality	150 m²	0,2 h/m²	30 h	1	4 d
Sanding drywalls	150 m²	0,05 h/m²	8 h	1	1 d
			144 h		18 d

Screed					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Cleaning the surface	40 m²	0,48 h/m²	19 h	1	2 d
Laying backfill	40 m²	0,76 h/m²	30 h	1	4 d
Sound insulation	40 m²	0,76 h/m²	30 h	1	4 d
Edge insulation strips	20 m	0,38 h/m	8 h	1	1 d
Seperating foil	40 m²	0,58 h/m²	23 h	1	3 d
			111 h		14 d

C

Drywall					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Separating strips	50 m²	0,12 h/m²	6 h	1	0,8 d
Closing shafts	30 m²	0,35 h/m²	11 h	1	1,3 d
Insulating drywall	300 m²	0,05 h/m²	15 h	1	1,9 d
Planking 2nd side	250 m²	0,045 h/m²	113 h	1	14,1 d
Applying first layer	250 m²	0,2 h/m²	50 h	1	6,3 d
Filling Q3-Quality	250 m²	0,2 h/m²	50 h	1	6,3 d
Sanding drywalls	150 m²	0,05 h/m²	8 h	1	0,9 d
			252 h		31 d

Screed					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Cleaning the surface	60 m²	0,48 h/m²	29 h	1	4 d
Laying backfill	60 m²	0,76 h/m²	46 h	1	6 d
Sound insulation	60 m²	0,76 h/m²	46 h	1	6 d
Edge insulation strips	30 m	0,38 h/m	11 h	1	1 d
Seperating foil	60 m²	0,58 h/m²	35 h	1	4 d
			166 h		21 d

A

Insulating drywall	100 m²	0,05 h/m²	5 h	5	0,1 d
Planking 2nd side	100 m²	0,045 h/m²	45 h	5	1,1 d
Applying first layer	100 m²	0,2 h/m²	20 h	5	0,5 d
Filling Q3-Quality	100 m²	0,2 h/m²	20 h	5	0,5 d
Sanding drywalls	100 m²	0,05 h/m²	5 h	5	0,1 d
			110 h		3 d

Sound insulation	25 m²	0,76 h/m²	19 h	2	1,2 d
Edge insulation strips	10 m	0,38 h/m	4 h	2	0,2 d
Seperating foil	25 m²	0,58 h/m²	15 h	2	0,9 d
			68 h		4 d

B

Drywall					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Separating strips	20 m²	0,12 h/m²	2 h	5	0,1 d
Closing shafts	25 m²	0,35 h/m²	9 h	5	0,2 d
Insulating drywall	150 m²	0,05 h/m²	8 h	5	0,2 d
Planking 2nd side	150 m²	0,045 h/m²	68 h	5	1,7 d
Applying first layer	100 m²	0,2 h/m²	20 h	5	0,5 d
Filling Q3-Quality	150 m²	0,2 h/m²	30 h	5	0,8 d
Sanding drywalls	150 m²	0,05 h/m²	8 h	5	0,2 d
			144 h		4 d

Screed					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Cleaning the surface	40 m²	0,48 h/m²	19 h	2	1,2 d
Laying backfill	40 m²	0,76 h/m²	30 h	2	1,9 d
Sound insulation	40 m²	0,76 h/m²	30 h	2	1,9 d
Edge insulation strips	20 m	0,38 h/m	8 h	2	0,5 d
Seperating foil	40 m²	0,58 h/m²	23 h	2	1,5 d
			111 h		7 d

C

Drywall					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Separating strips	50 m²	0,12 h/m²	6 h	5	0,2 d
Closing shafts	30 m²	0,35 h/m²	11 h	5	0,3 d
Insulating drywall	300 m²	0,05 h/m²	15 h	5	0,4 d
Planking 2nd side	250 m²	0,045 h/m²	113 h	5	2,8 d
Applying first layer	250 m²	0,2 h/m²	50 h	5	1,3 d
Filling Q3-Quality	250 m²	0,2 h/m²	50 h	5	1,3 d
Sanding drywalls	150 m²	0,05 h/m²	8 h	5	0,2 d
			252 h		6 d

Screed					
BoQ Item	Amount	Consumption rate	h^T_j	Crew Size	Duration
Cleaning the surface	60 m²	0,48 h/m²	29 h	2	1,8 d
Laying backfill	60 m²	0,76 h/m²	46 h	2	2,9 d
Sound insulation	60 m²	0,76 h/m²	46 h	2	2,9 d
Edge insulation strips	30 m	0,38 h/m	11 h	2	0,7 d
Seperating foil	60 m²	0,58 h/m²	35 h	2	2,2 d
			166 h		10 d

Appendix A.3. Calculation simplified Example 'Drywall' and 'Screed' for Takt planning

Taktarea | CW = 40h (5 days á 8h) | CW = 40h (5 days á 8h)

Taktarea A

Drywall

Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	50 m²	0,12 h/m²	3	2 h
Closing shafts	25 m²	0,35 h/m²	3	3 h
Insulating drywall	100 m²	0,05 h/m²	3	3 h
Planking 2nd side	100 m²	0,45 h/m²	3	15 h
Applying first layer	100 m²	0,2 h/m²	3	7 h
Filling Q3-Quality	100 m²	0,2 h/m²	3	7 h
Sanding drywalls	100 m²	0,05 h/m²	3	2 h
			D_x	38 h
			cp_x	0,95

$$D_x = \frac{V_x \times R^C}{8\left[\frac{h}{d}\right] \times C}$$

Screed

Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	25 m²	0,48 h/m²	3	2 h
Laying backfill	25 m²	0,76 h/m²	3	3 h
Sound insulation	25 m²	0,76 h/m²	3	2 h
Edge insulation strips	10 m	0,38 h/m	3	15 h
Seperating foil	25 m²	0,58 h/m²	3	7 h
			D_x	25 h
			cp_x	0,62

$$W_x \hat{=} TT$$

$$W_x: 0,8 \geq \frac{D_x}{TT} = cp_x \leq 0,95$$

Taktarea B

Drywall

Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	20 m²	0,12 h/m²	4	1 h
Closing shafts	25 m²	0,35 h/m²	4	3 h
Insulating drywall	150 m²	0,05 h/m²	4	2 h
Planking 2nd side	150 m²	0,45 h/m²	4	17 h
Applying first layer	100 m²	0,2 h/m²	4	5 h
Filling Q3-Quality	150 m²	0,2 h/m²	4	8 h
Sanding drywalls	150 m²	0,05 h/m²	4	2 h
			D_x	36 h
			cp_x	0,90

Screed

Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	40 m²	0,48 h/m²	5	4 h
Laying backfill	40 m²	0,76 h/m²	5	6 h
Sound insulation	40 m²	0,76 h/m²	5	6 h
Edge insulation strips	20 m	0,38 h/m	5	2 h
Seperating foil	40 m²	0,58 h/m²	5	5 h
			D_x	22 h
			cp_x	0,55

Taktarea C

Drywall

Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	50 m²	0,12 h/m²	6	1 h
Closing shafts	30 m²	0,35 h/m²	6	2 h
Insulating drywall	300 m²	0,05 h/m²	6	3 h
Planking 2nd side	250 m²	0,45 h/m²	6	19 h
Applying first layer	250 m²	0,2 h/m²	6	8 h
Filling Q3-Quality	250 m²	0,2 h/m²	6	8 h
Sanding drywalls	150 m²	0,05 h/m²	6	2 h
			D_x	43 h
			cp_x	1,08

Screed

Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	60 m²	0,48 h/m²	6	5 h
Laying backfill	60 m²	0,76 h/m²	6	8 h
Sound insulation	60 m²	0,76 h/m²	6	8 h
Edge insulation strips	30 m	0,38 h/m	6	2 h
Seperating foil	60 m²	0,58 h/m²	6	6 h
			D_x	28 h
			cp_x	0,7

"Wagon"-level formula not achieved.

Taktarea	CW = 40h (5 days á 8h)	CW = 40h (5 days á 8h)
A	Drywall 1	Drywall 2; Screed 1
B	Drywall 1	Drywall 2; Screed 1
C	Drywall 1	Drywall 2; Screed 1

Taktarea A

Drywall 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	50 m²	0,12 h/m²	3	2 h
Closing shafts	25 m²	0,35 h/m²	3	3 h
Insulating drywall	100 m²	0,05 h/m²	3	3 h
Planking 2nd side	100 m²	0,45 h/m²	3	15 h
Applying first layer	100 m²	0,2 h/m²	3	7 h
			D_x	32 h
			cp_x	0,8

Splitting work package to balance wagon with capacity buffer.

Drywall 2				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Filling Q3-Quality	100 m²	0,2 h/m²	2	10 h
Sanding drywalls	100 m²	0,05 h/m²	2	3 h
			D_x	13 h

Screed 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	25 m²	0,48 h/m²	3	2 h
Laying backfill	25 m²	0,76 h/m²	3	3 h
Sound insulation	25 m²	0,76 h/m²	3	2 h
Edge insulation strips	10 m	0,38 h/m	3	15 h
Seperating foil	25 m²	0,58 h/m²	3	7 h
			D_x	25 h
			cp_x	0,95

Taktarea B

Drywall 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	50 m²	0,12 h/m²	3	1 h
Closing shafts	25 m²	0,35 h/m²	3	3 h
Insulating drywall	100 m²	0,05 h/m²	3	3 h
Planking 2nd side	100 m²	0,45 h/m²	3	23 h
Applying first layer	100 m²	0,2 h/m²	3	7 h
			D_x	37 h
			cp_x	0,93

Drywall 2				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Filling Q3-Quality	150 m²	0,2 h/m²	3	8 h
Sanding drywalls	150 m²	0,05 h/m²	3	2 h
			D_x	10 h

Screed 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	40 m²	0,48 h/m²	5	4 h
Laying backfill	40 m²	0,76 h/m²	5	6 h
Sound insulation	40 m²	0,76 h/m²	5	6 h
Edge insulation strips	20 m	0,38 h/m	5	2 h
Seperating foil	40 m²	0,58 h/m²	5	5 h
			D_x	22 h
			cp_x	0,8

Taktarea C

Drywall 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Separating strips	50 m²	0,12 h/m²	6	1 h
Closing shafts	25 m²	0,35 h/m²	6	2 h
Insulating drywall	300 m²	0,05 h/m²	6	3 h
Planking 2nd side	250 m²	0,45 h/m²	6	19 h
Applying first layer	250 m²	0,2 h/m²	6	8 h
			D_x	33 h
			cp_x	0,83

Drywall 2				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Filling Q3-Quality	250 m²	0,2 h/m²	6	8 h
Sanding drywalls	250 m²	0,05 h/m²	6	2 h
			D_x	10 h

Screed 1				
Work steps	Amount	Consumption rate	Crew Size	Workhours
Cleaning the surface	60 m²	0,48 h/m²	7	4 h
Laying backfill	60 m²	0,76 h/m²	7	7 h
Sound insulation	60 m²	0,76 h/m²	7	7 h
Edge insulation strips	30 m	0,38 h/m	7	2 h
Seperating foil	60 m²	0,58 h/m²	7	5 h
			D_x	24 h
			cp_x	0,85

Appendix A.3. Case Study - Input data for calculations

This appendix lists the quantitative input data used in the case study example, allowing replication of the calculation steps.

Sequence of activities		Areas		Southeast				Southwest				Northeast				Northwest				Center			
		Floor		1	2	3	Roof	1	2	3	Roof	1	2	3	Roof	1	2	3	Roof	1	2	3	Roof
	Item	Consumption Rate (man hours per unit) RCi,j		Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]	Quantitiy Qi,j [m²]
1	**TOP TRACK, BEAM CLAMPS ETC.**	**0,25**	Length	1000	1000	1000	0	650	650	650	0	1000	1000	1000	0	650	650	650	0				1500
2	**Fireproofing**	**0,02**	Side Area	35000	35000	35000		24000	24000	24000		35000	35000	35000		24000	24000	24000		8000			
3	**Frame priority fullheight walls etc.**	**0,25**	Height	1000	1000	1000	0	650	650	650	0	1000	1000	1000	0	650	650	650					
4	**Sprinkler Rough**	**0,07**	Length	2120	2120	2120		1400	1400	1400		2120	2120	2120		1400	1400	1400					
5	**Medium pressure duct**	**0,1**	Length	500	500	500		350	350	350		500	500	500		350	350	350					
6	**Mechanical Rough**	**0,1**	Length	1500	1500	1500		1000	1000	1000		1500	1500	1500		1000	1000	1000					
7	**VAV and Low Pressure Ducts**	**0,1**	Length	4000	4000	4000		2650	2650	2650		4000	4000	4000		2650	2650	2650					
8	**Dom Water**	**0,07**	Length	2000	2000	2000		1400	1400	1400		2000	2000	2000		1400	1400	1400					
9	**Rain Water Leaders, Waste and Vent**	**0,04**	Length	2500	2500	2500		1700	1700	1700		2500	2500	2500		1700	1700	1700					
10	**Branch conduit**	**0,064**	Length	3000	3000	3000	3000	2500	2500	2500	2500	3000	3000	3000	3000	2500	2500	2500	2500	1000	1000	1000	1000
11	**Feeder conduit**	**0,1**	Length	2000	2000	2000	2000	1500	1500	1500	1500	2000	2000	2000	2000	1500	1500	1500	1500	750	750	750	750
12	**Wall, Hard Ceiling, and Soffit Framing**	**0,04**	Side Area	1900	1900	1900	0	1300	1300	1300	0	1900	1900	1900	0	1300	1300	1300	0				3000
13	**Wall, Hard Ceiling, and soffit MEP Roughins**	**0,3**	Count	25	25	25	0	15	15	15	0	25	25	25	0	15	15	15	0	0	0	0	40
14	**MED GAS**	**0,07**	Length					0	0	0	0	0	0	0	0	2000	0	0	0	0	0	0	0
15	**Cable Tray**	**0,053**	Length	250	250	250	250	160	160	160	160	250	250	250	250	160	160	160	160	50	50	50	50
16	**Tele/data, Nurse Call, Security, AV, and Fire Alarm**	**0,008**	Length	3000	3000	3000		2500	2500	2500	0	3000	3000	3000	0	2500	2500	2500	0	1000	1000	1000	0
17	**Drywall**	**0,013**	Side Area	36000	36000	36000	0	24000	24000	24000		36000	36000	36000	0	24000	24000	24000	0	8000	8000	8000	8000
18	**Tape and Finish**	**0,007**	Side Area	36000	36000	36000	0	24000	24000	24000		36000	36000	36000	0	24000	24000	24000	0	8000	8000	8000	8000
19	**Paint**	**0,008**	Side Area	36000	36000	36000	0	24000	24000	24000		36000	36000	36000	0	24000	24000	24000	0	8000	8000	8000	8000
20	**T-Bar**	**0,014**	Side Area	30000	30000	30000	0	20000	20000	20000	0	30000	30000	30000	0	20000	20000	20000	0	5000	5000	5000	0
21	**Light Fixtures, Diffusers, Ceiling Mounted Trim**	**0,5**	Count	464	464	464	450	354	354	354	350	464	464	464	450	354	354	354	350	100	100	100	100
22	**Ceiling tile**	**0,007**	Floor Area	30000	30000	30000		20000	20000	20000		30000	30000	30000		20000	20000	20000					
23	**Casework, Millwork**	**0,2**	Length	2000	2000	2000		1300	1300	1300		2000	2000	2000		1300	1300	1300		1075	1075	1075	
24	**MEP Trim**	**0,5**	Count	75	75	75	0	50	50	50	0	75	75	75	0	50	50	50	0	25	25	25	25
25	**Floor coverings**	**0,018**	Floor Area	30000	30000	30000		20000	20000	20000		30000	30000	30000		20000	20000	20000		5000	5000	5000	0
26	**Specialties and accessories**	**0,2**	Count	75	100	100	5	75	100	100	5	75	100	100	5	50	75	75	5	5	5	5	0
27	**Doors & Hardware**	**0,9**	Count	75	100	100	5	75	100	100	5	75	100	100	5	50	75	75	5	5	5	5	0

Sequence of activities		Areas		Southeast				Southwest				Northeast				Northwest				Center			
		Floor		1	2	3	Roof	1	2	3	Roof	1	2	3	Roof	1	2	3	Roof	1	2	3	Roof
	Item	Consumption Rate (man hours per unit) RCi,j		Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h	Dx in h
1	**TOP TRACK, BEAM CLAMPS ETC.**	**0,25**	Length	250	250	250	0	162,5	162,5	162,5	0	250	250	250	0	162,5	162,5	162,5	0	0	0	0	375
2	**Fireproofing**	**0,02**	Side Area	700	700	700	0	480	480	480	0	700	700	700	0	480	480	480	0	160	0	0	0
3	**Frame priority fullheight walls etc.**	**0,25**	Height	250	250	250	0	162,5	162,5	162,5	0	250	250	250	0	162,5	162,5	162,5	0	0	0	0	0
4	**Sprinkler Rough**	**0,07**	Length	148,4	148,4	148,4	0	98	98	98	0	148,4	148,4	148,4	0	98	98	98	0	0	0	0	0
5	**Medium pressure duct**	**0,1**	Length	50	50	50	0	35	35	35	0	50	50	50	0	35	35	35	0	0	0	0	0
6	**Mechanical Rough**	**0,1**	Length	150	150	150	0	100	100	100	0	150	150	150	0	100	100	100	0	0	0	0	0
7	**VAV and Low Pressure Ducts**	**0,1**	Length	400	400	400	0	265	265	265	0	400	400	400	0	265	265	265	0	0	0	0	0
8	**Dom Water**	**0,07**	Length	140	140	140	0	98	98	98	0	140	140	140	0	98	98	98	0	0	0	0	0
9	**Rain Water Leaders, Waste and Vent**	**0,04**	Length	100	100	100	0	68	68	68	0	100	100	100	0	68	68	68	0	0	0	0	0
10	**Branch conduit**	**0,064**	Length	192	192	192	192	160	160	160	160	192	192	192	192	160	160	160	160	64	64	64	64
11	**Feeder conduit**	**0,1**	Length	200	200	200	200	150	150	150	150	200	200	200	200	150	150	150	150	75	75	75	75
12	**Wall, Hard Ceiling, and Soffit Framing**	**0,04**	Side Area	76	76	76	0	52	52	52	0	76	76	76	0	52	52	52	0	0	0	0	120
13	**Wall, Hard Ceiling, and soffit MEP Roughins**	**0,3**	Count	7,5	7,5	7,5	0	4,5	4,5	4,5	0	7,5	7,5	7,5	0	4,5	4,5	4,5	0	0	0	0	12
14	**MED GAS**	**0,07**	Length	0	0	0	0	0	0	0	0	0	0	0	0	140	0	0	0	0	0	0	0
15	**Cable Tray**	**0,053**	Length	13,25	13,25	13,25	13,25	8,48	8,48	8,48	8,48	13,25	13,25	13,25	13,25	8,48	8,48	8,48	8,48	2,65	2,65	2,65	2,65
16	**Tele/data, Nurse Call, Security, AV, and Fire Alarm**	**0,008**	Length	24	24	24	0	20	20	20	0	24	24	24	0	20	20	20	0	8	8	8	0
17	**Drywall**	**0,013**	Side Area	468	468	468	0	312	312	312	0	468	468	468	0	312	312	312	0	104	104	104	104
18	**Tape and Finish**	**0,007**	Side Area	252	252	252	0	168	168	168	0	252	252	252	0	168	168	168	0	56	56	56	56
19	**Paint**	**0,008**	Side Area	288	288	288	0	192	192	192	0	288	288	288	0	192	192	192	0	64	64	64	64
20	**T-Bar**	**0,014**	Side Area	420	420	420	0	280	280	280	0	420	420	420	0	280	280	280	0	70	70	70	0
21	**Light Fixtures, Diffusers, Ceiling Mounted Trim**	**0,5**	Count	232	232	232	225	177	177	177	175	232	232	232	225	177	177	177	175	50	50	50	50
22	**Ceiling tile**	**0,007**	Floor Area	210	210	210	0	140	140	140	0	210	210	210	0	140	140	140	0	0	0	0	0
23	**Casework, Millwork**	**0,2**	Length	400	400	400	0	260	260	260	0	400	400	400	0	260	260	260	0	215	215	215	0
24	**MEP Trim**	**0,5**	Count	37,5	37,5	37,5	0	25	25	25	0	37,5	37,5	37,5	0	25	25	25	0	12,5	12,5	12,5	12,5
25	**Floor coverings**	**0,018**	Floor Area	540	540	540	0	360	360	360	0	540	540	540	0	360	360	360	0	90	90	90	0
26	**Specialties and accessories**	**0,2**	Count	15	20	20	1	15	20	20	1	15	20	20	1	10	15	15	1	1	1	1	0
27	**Doors & Hardware**	**0,9**	Count	67,5	90	90	4,5	67,5	90	90	4,5	67,5	90	90	4,5	45	67,5	67,5	4,5	4,5	4,5	4,5	0
			Sum	5631	5659	5659	636	3860	3888	3888	499	5631	5659	5659	636	3973	3860	3860	499	977	817	817	935
			Overall	**63042** workhours																			

Appendix A.4. Calculation of workforce variability

This appendix describes the derivation and calculation of workforce variability metrics used in the quantitative comparison of LBMS and Takt planning. Workforce variability is quantified using the sample standard deviation and the coefficient of variation (CV), based on weekly mobilized workforce data.

A.4.1 Data basis

The calculations are based on the weekly mobilized workforce extracted from the case study schedules for LBMS and Takt planning (Figure 10).
Let:

- w_t= number of mobilized workers in week t
- $t = 1, \dots, n$= index of active project weeks

Only active project weeks are considered in the analysis, defined as weeks with:

$$w_t > 0$$

Weeks with zero workforce (before project start or after project completion) are excluded to avoid distortion of workforce variability metrics.

Here the week t with w_t:

Week t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Takt w_t	8	14	14	18	18	20	20	22	25	28	31	32	34	35	38	38	38	40	44	48	49	50	54	53	60	59	51	52	54	50	59
LBMS w_t	4	14	14	14	14	18	18	18	18	21	22	22	25	33	33	38	36	38	38	26	26	26	26	22	22	19	29	29	30	30	27

Week t	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Takt w_t	54	52	57	54	47	50	50	55	58	42	50	46	36	36	28	29	27	29	20	20	16	11	11	5	5	5	3	0	0	0	0
LBMS w_t	19	19	20	15	15	24	33	33	36	37	39	34	35	46	40	40	40	32	32	33	23	23	24	23	17	17	17	17	5	4	0

A.4.2 Mean weekly workforce

The mean weekly workforce $\bar{w}$is calculated as:

$$\bar{w} = \frac{1}{n} \sum_{t=1}^{n} w_t$$

where: n is the number of active project weeks.

- Takt n = 58
- LBMS n = 61

A.4.3 Workforce variability – standard deviation

Workforce variability is first expressed as the sample standard deviation of weekly workforce levels:

$$s = \sqrt{\frac{1}{n-1}\sum_{t=1}^{n}(w_t - \bar{w})^2}$$

The sample standard deviation is used because the observed weekly workforce values represent a realization of project execution rather than a complete population.

Unit: workers/week

A.4.4 Workforce variability – coefficient of variation (CV)

To enable comparison between planning approaches with different average workforce levels, variability is additionally reported as the coefficient of variation (CV):

$$CV = \frac{s}{\bar{w}}$$

The coefficient of variation is a dimensionless measure that normalizes workforce variability relative to the mean workforce level. It is particularly appropriate for comparing variability between scheduling approaches with differing workforce magnitudes.