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WORKFLOW ISSUE IDENTIFICATION BY APPLYING LOCATION-BASED WORK SAMPLING

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ABSTRACT

This study examines Location-Based Work Sampling (LBWS) to improve construction site management by identifying workflow issues. For that, a Case Study was conducted on a Danish new building project, and the workflows of three trades were observed. The LBWS application presented a structured four-step methodology: (1) activity and workspace identification; (2) data collection; (3) data visualization; and (4) data analysis. For the LBWS application, the "Ajour system" app was selected as the optimal software based on the technique "Choosing by Advantages". At the data collection step, the authors registered 994 random observations of worker activities classified into six work activity categories (production, preparation, transportation, walking, talking, and waiting) and into four workspace categories (production, preparation, storage, and transportation workspace). Previous LBWS studies used a single workspace categorization. This study introduces a grid-based system to capture production dynamics. This study highlights LBWS as a powerful tool for optimizing workflows by identifying inefficiencies. It provides insights into (1) work activity analysis, differentiating value-added vs. non-value-added tasks, reducing excessive walking and waiting times; (2) workspace and resource utilization, using heat maps to assess labor and material distribution; and (3) interferences and congestion, identifying workflow bottlenecks caused by overcrowding or mismanagement.

KEYWORDS

Location-based Work Sampling, workflow, heat map, job site.

INTRODUCTION AND BACKGROUND

The term workflow has been widely used in the Lean Construction community. The widespread use of the term of flow in production and logistics seems a good reason to invest effort in unpacking an appropriate concrete meaning of the term as it relates to the thinking surrounding construction industry production and daily operations (Kalsaas & Bølviken, 2010).

More than twenty-five years have passed since Koskela (2000) stated that methods and practices based on the workflow concept have become widespread; however, the concept itself has not been widely acknowledged. A more recent literature review study indicates that workflow's definition remains unclear and imprecise, with only a limited number of effective measurement methods available (Pérez et al., 2014). In the present study, workflow is related

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to the worker flow (or people flow) defined by Tommelein et al. (2022); it captures the path a worker travels in the course of their workday. People come to work and go home each day, attend team meetings, and go to the workforce - the location where they install materials and products in their final position (called production workspace in this study) or other locations to perform work, take breaks, etc. Bolviken and Kalsaas (2011) argue that measuring workflow as directly as possible is essential. However, a combination of direct and indirect measurements may offer a viable solution. Additionally, measurement methods can be categorized based on whether they involve self-assessment, which is more subjective, or observations of others, which are more neutral. Each approach has its own advantages and disadvantages. In this context, Bolviken and Kalsaas (2011) outline ten strategies for measuring workflow, three of which rely on self-assessment and seven on observing others.

The self-assessment measurement strategies presented by Bolviken and Kalsaas (2011) are: (1) the actors' perception of work stoppages (extent and causes); (2) the actors' perception of the degree of workflow; and (3) the actors' perception of the distribution between flow, making do, and stoppages. The third-party observation measurement strategies are: (1) a Percentage of Plan Completed (PPC); (2) actual time used compared to estimate; (3) perfect person-to-person handover of work; (4) perfect handover of work between trades; (5) detailed breakdown of planned activities and individual studies of time use (also called work sampling); (6) piece-work earnings and (7) turnover per person per time unit.

Over the years, the Work Sampling (WS) technique has become the most widespread technique for measuring workflow. This technique has long been employed to understand how workers spend their time on various tasks, providing insights into labour efficiency and workflow (Barnes, 1968). However, WS has often been limited by its lack of spatial consideration, focusing solely on the categorization of work activities without addressing the specific locations where these activities occur (Pérez et al., 2022).

Alternatively, video-based work sampling allows the application of time-motion studies providing information about the task and the place where the activity is performed. Time-motion studies can examine workflows, including their share of direct work, and analyze causes of interruptions. Time-motion data can be seen as a quantitative and digital representation of an installers individual workflow based on real-time data. However, the analysis requires a high manual effort and is not done in real-time (Görsch et al., 2022a). In this way, Gõrsch et al. (2022a; 2022b) aimed to collect workflow data through the realization of a time-motion study in order to analyze the causes and effects of workflow interruptions. However, their study was limited to understanding the workflow issues of a single individual worker of a single trade (e.g., plumber trade). Consequently, the study has reduced scalability to other trades. Moreover, understanding the workflows of one trade does not allow the construction site manager to provide a comprehensive understanding of all the existing workflows and how they impact each other. Therefore, understanding where workers spend their time is crucial for workspace management and workflow issue identification. In this way, Zhao et al. (2020) proposed the use of heat maps on workers´onsite presence as an alternative to eliminate waste related to product and labor flows.

To address the lack of spatial representation of the workflow efficiency using WS, Pérez et al. (2022) presented a novel adaptation of the WS known as Location-Based Work Sampling (LBWS). LBWS integrates geographic information into WS, resulting in geolocated observations. This technique aims to visualize" how" and "where" workers spend their time on construction sites, thereby offering a more comprehensive analysis of job site activities (Pérez et al., 2023). By mapping these observations onto the job site layout, LBWS facilitates a deeper understanding of workflows, which might enable the identification of workflow issues such as excessive time spent on tasks that do not add value, excessive walking and waiting times, poor workspace and resource utilization, and interferences and congestion. Despite its benefits, implementing LBWS presents challenges, particularly in data collection and the accuracy of geographic coordinates. Moreover, previous applications have limited understanding distribution of time into work activities and worskspace. But, other possible uses can. This study aims to investigate answers to the research question:

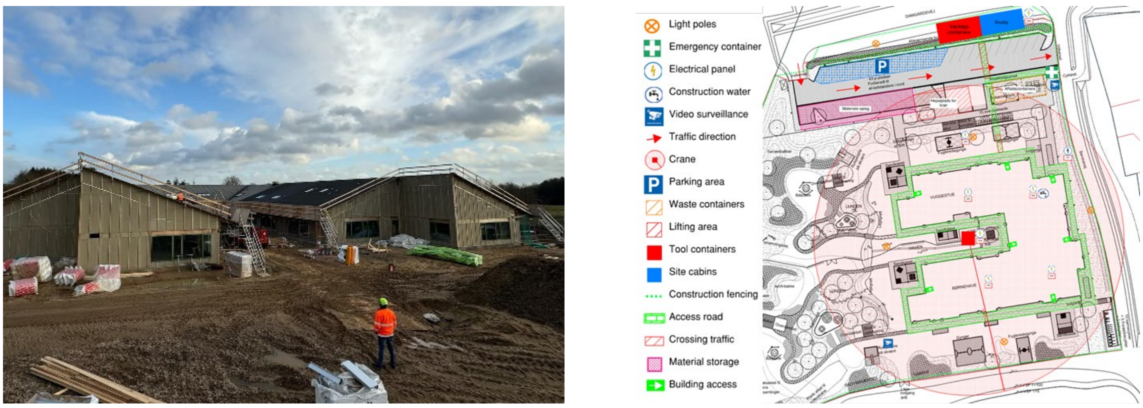
- How can LBWS be utilized to identify workflow issues within construction management?

RESEARCH METHODOLOGY

The authors used the Case Study (Yin, 2003) as the primary research method, as case studies offer flexibility for explorative research in real life. The case study allowed the authors to explore a new tool in depth and analyze its use, benefits, and overall effectiveness. The Case Study methodology consists of five phases: (1) plan the study; (2) design the case; (3) prepare the data collection; (4) collect data; and (5) analyze and report findings.

PHASES 1 AND 2: PLAN THE STUDY AND DESIGN THE CASE

During the first two phases, the authors identify the type of case and the project for the study. The Case Study was the construction of a single-story building for a kindergarten and a nursery (Figure 1). The primary reasons for selecting this project were the shorter approval process for applying the tool, the recognition that the project was behind schedule, and the authors' eagerness to assess the ease or complexity of interpreting results in a relatively small project. This access was crucial for conducting a thorough and well-informed analysis, allowing them to gain deeper insights into the company's operations and decision-making processes. Moreover, the company provided access to project-related documents, observation of routine activities, and interaction with team members. Hence, the real-life context is presented by the housing project under construction. The phenomena of the study are the workflows of three trades conducting activities during the period of the study: structural carpenters, interior carpenters, and roofing specialists.



(a) (b)

Figure 1: Case of the study: (a) Jobsite photo and (b) Site layout

PHASE 3: PREPARE THE DATA COLLECTION

In previous LBWS studies (Pérez et al., 2023), two tools were utilized to record data. First, work activities and workspaces were collected using MS Excel and a tally counter. Then, GPS location from an image was extracted to pinpoint observation locations. Hence, observers had to record activity data in the data collection sheets and capture a photograph using a mobile phone. This process was time-consuming, and if the observer had not been close enough to the worker, this could have introduced errors in the location recorded. Since the observer had to be as close to the worker as possible, this data collection method could also disrupt the workers.

Table 1: CBA steps for the selection of the tool for the LBWS application

Factor & Criterion	MS Excel	Imp	AppSheets	Imp	Dalux app	Imp	Ajour system	Imp
1. Database creation	Att: Export in .xls file		Att: Export in.gsheet		Att: Export in .csv file		Att: Export in .csv file	
Crit: The faster data process the better	Adv.: Enabling further data processing	Imp: 90	Adv.: Enabling further data processing	Imp: 90	Adv.: Enabling further data processing	Imp: 90	Adv.: Enabling further data processing	Imp: 90
2. Linking database to UI	Att: Databases organized in different validation and formulas must be used		Att: opportunities to create a user interface for data		Att: No opportunities to create database UI		Att: opportunities to create a user interface for data	
Crit: The easier use the better	Adv.:	Imp: 0	Adv.: Easy navigation	Imp: 75	Adv.:	Imp :0	Adv.: Good link DB to the UI	Imp: 75
3. Database editing	Att: Manually changes		Att: Manually changes		Att: Automatic changes		Att: Manually changes	
Crit: The easier use the better	Adv.:	Imp: 0	Adv.:	Imp: 0	Adv.: Straight forward	Imp: 20	Adv.:	Imp: 0
4. UI / Data recording	Att: The software facilitates all criteria		Att: The software facilitates all criteria		Att: No breakdown list for data		Att: The software facilitates all criteria	
Crit: The easier data recording the better	Adv.:	Imp: 0	Adv.: It's a mobile app. Navigation is easy. less time consuming	Imp: 90	Adv.:	Imp: 0	Adv.: It's a mobile app. Navigation is easy. less time consuming	Imp: 90
5. Storing/ exporting	Att: Data stored in MS Excel created		Att: Data stored in the Google sheet created		Att: Saved in the app.		Att: Saved in the app.	
Crit: The less creation of files the better	Adv.: Data stored in the same MS Excel sheet created.	Imp: 25	Adv.: Data stored in the same Google sheet, less time consuming	Imp: 25	Adv.:	Imp: 0	Adv.:	Imp: 0
6. Location reference	Att: A photograph must be captured with "EXIF" data		Att: Google location service can be used.		Att: Location can be marked on the site layout imported.		Att: Location can be marked on the site layout imported.	
Crit: The automatic link the better	Adv.:	Imp: 0	Adv.:	Imp: 0	Adv.: GPS location also can be recorded within the app	Imp: 75	Adv.: GPS location also can be recorded within the app	Imp: 75
7. Location recording	Att: Must go as closer to the worker to get accurate location.		Att: Must go as closer to the worker to get accurate location.		Att: No need to go near the workers.		Att: No need to go near the workers.	
Crit: The automatic geo. the better	Adv.:	Imp: 0	Adv.:	Imp: 0	Adv.: Can stand from a distance and collect data	Imp: 35	Adv.: Can stand from a distance and collect data	Imp: 35
8. VM and presentation	Att: Must use a separate data visualization tool.		Att: Must use a separate data visualization tool.		Att: Can be visualized in the app and exported. But has its limitations.		Att: Can be visualized in the app and exported. But has its limitations.	
Crit: The better illustrations the better	Adv.:	Imp: 0	Adv.:	Imp: 0	Adv.: The software has an Built-in tool	Imp: 10	Adv.: The software has an Built-in tool	Imp: 10
9. Preferred device	Att: iPad/tablet is more suitable.		Att: Phone or iPad/tablet can be used.		Att: Phone or iPad/tablet can be used.		Att: Phone or iPad/tablet can be used.	
Crit: The less disturbing the better	Adv.:	Imp: 0	Adv.: minimum disturbance	Imp: 25	Adv.: minimum disturbance	Imp: 25	Adv.: minimum disturbance	Imp: 25
10. Internet access	Att: No need of internet at the time of data recording		Att: Need access to internet.		Att: No need of internet at the time of data recording		Att: No need of internet at the time of data recording	
Crit: The better Internet con. the better	Adv.: data can be extracted when device has internet con.	Imp: 20	Adv.:	Imp: 20	Adv.: data can be extracted when device has internet con.	Imp: 20	Adv.: data can be extracted when the device has internet con	Imp: 20
Total IofA		135		325		275		420

Crit: Criteria, Att: Attribute, Adv.: Advantage, Imp: Importance; UI: User Interface; VM: Visual Management

Therefore, the data collection of the present study adopted a method that can simplify the process and cause minimal distractions to the workers. To determine the optimal tool that can overcome said drawbacks, the technique "Choosing by Advantages" (CBA) by Arroyo was used (Arroyo et al., 2014). Adapting to Arroyo's method, the selection process was conducted in seven steps: (1) identify alternatives; (2) define factors (ten in this case); (3) define must/want to have criteria; (4) summarize the attributes of each alternative; (5) decide the advantages; (6) decide the importance of each advantage; and (7) evaluate money data. For this study, the author identified four possible alternative software: (1) MS Excel, (2) AppSheets, (3) Dalux app, and (4) Ajour system. The alternative with the highest total importance was the Ajour system, with a Total Importance (ToI) of 420 (Table 1). The Ajour System is a digital platform designed to enhance construction management, documentation, and workflow optimization. It provides a structured approach to collecting, organizing, and analyzing data.

PHASES 4 AND 5: COLLECT THE DATA AND REPORT FINDINGS

This study's fourth and fifth phases consist of applying LWBS. The application of LBWS involved four main steps (Figure 2): (1) activity and workspace identification; (2) data collection; (3) data visualization; and (4) data analysis.

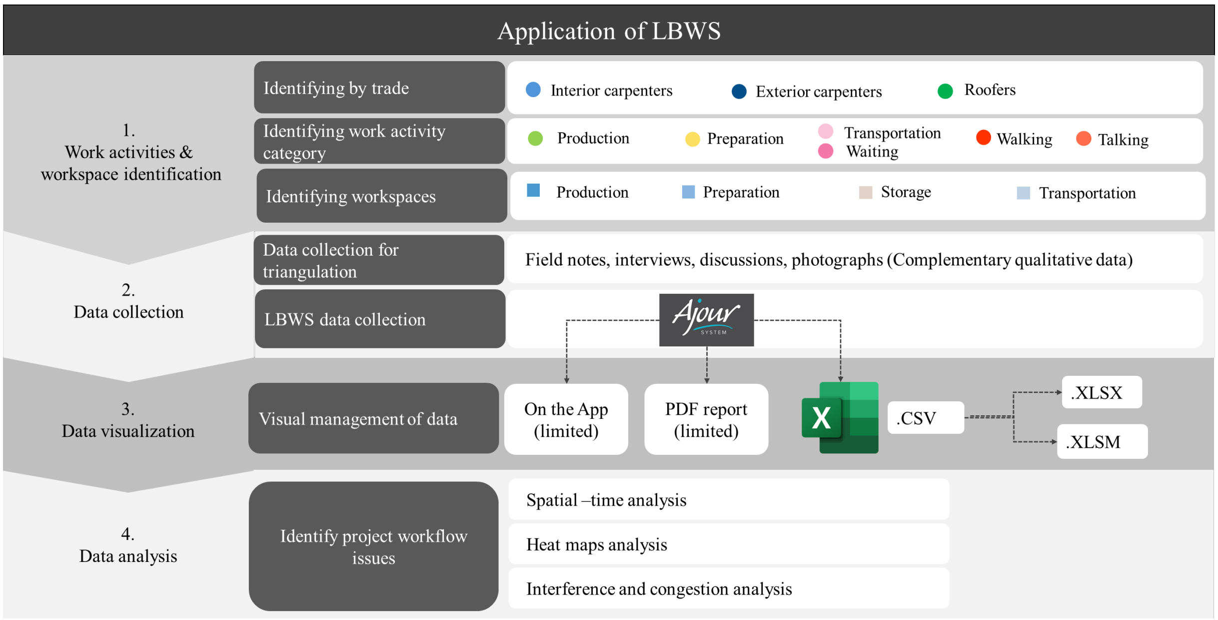
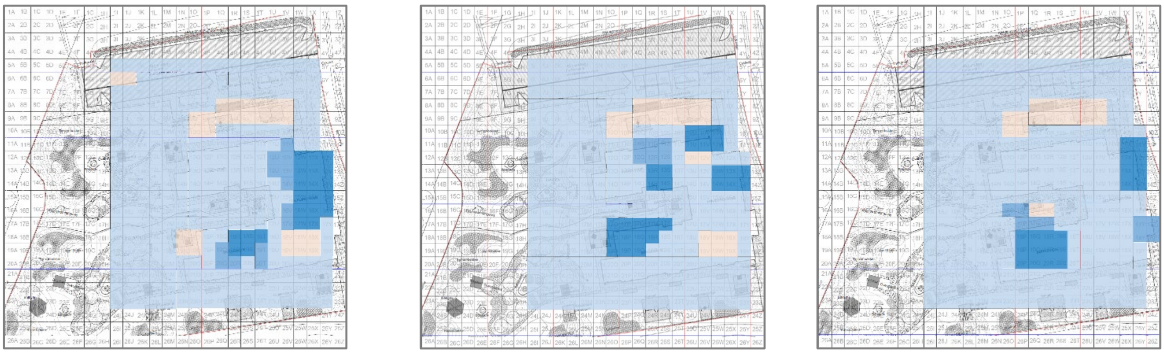


Figure 2: Steps LBWS application

Step 1: Clarifying the Work Activities and the Workspaces

This study classified the work activities into six: (1) production, (2) preparation, (3) transportation, (4) walking, (5) talking, and (6) waiting. These six work activity categories were considered optimum as they ensure consistency with previous studies conducted by the present team of researchers, provide comprehensive coverage of key construction activities, and maintain a balance between simplicity and detail for efficient data collection and analysis. In addition, this study adopted a four-category classification of the jobsite into workspaces: (1) production (dark blue in Figure 3); (2) preparation (light blue color in Figure 3); (3) storage; (pink color in Figure 3); and (4) transportation (the lighter blue in Figure 3). This categorization was used since it provided a clear distinction between key jobsite functions while maintaining simplicity for effective spatial analysis. These classifications were applied consistently across all trades observed during the LBWS ap provide a clear distinction between key jobsite functions, and maintain a balance between simplicity and detail for effective spatial analysis aplication period to provide a structured approach to analyzing both work activities and spatial organization on the construction site.

Previous studies that applied the LBWS adopted one single workspace categorization for the entire project and all trades. As a new approach, this study used a grid system to classify the workspaces of the jobsite to consider the dynamic nature of the production activities (Figure 3). The grid consists of horizontal and vertical lines, forming a structured layout of cells. The horizontal axis is labeled with letters (e.g., A, B, etc.), while the vertical axis is labeled with numbers (e.g., 1, 2, etc.). Each cell within the grid is identified by a unique combination of a letter and a number, similar to a spreadsheet format (e.g., the top-left cell is A1; column A, row 1). This approach enhances clarity when discussing changes on workspaces categories. Example of the use of grid labelling is shown in Table 2.



(a) (b) (c)

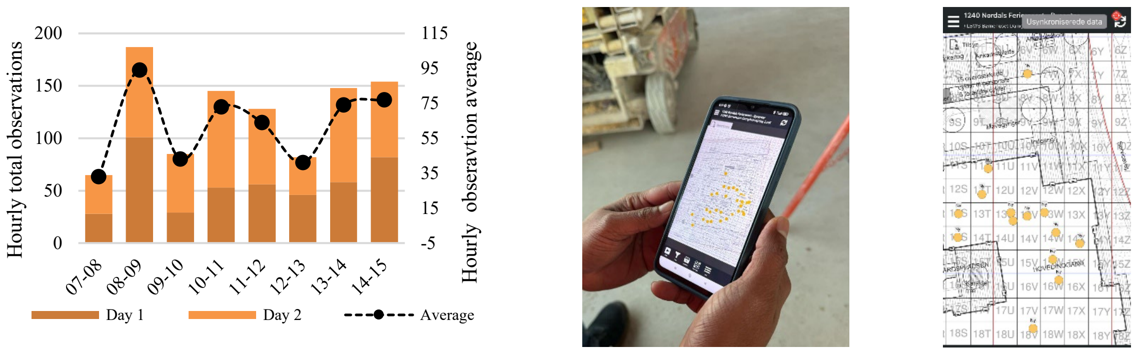
Figure 3: Workspace definition for: (a) Interior carpenters; (b) Exterior carpenters; and (c) Roofers

Table 2: Example of the use of the grid to track shared spaces and use.

Cells	Workspace	Usage		
		Interior carpenters	Exterior carpenters	Roofers
W13, W14, X13, X14, Y13, Y14, R18	Production	√	√	
O9, O10, P9, P10, Q8, Q9, R8, R9, S8, S9	Storage	√	√	√
U12, V12 & V18, V19, W18, W19, X18, X19	Storage	√	√	
P17, P17, R17	Production & Preparation		√	√

Step 2: Data collection

The authors selected two working days for data collection at the end of November 2024. Due to the scale of the construction project and the number of workers and trades involved, additional days were considered unnecessary.



(a) (b) (c)

Figure 4: Data collection: (a) Sample characterization; (b) Looks of the Ajour system; and (c) Observations registered on the grid over the jobsite layout

Based on the "Guide to Activity Analysis" (CII, 2010), with 00-51 workers on-site, a minimum of 46 observations per hour was required. The total observations made were 994 (Figure 4a).During the data collection, observations were made regarding the three different trades on the site: exterior carpenters (n=315), interior carpenters (n=612), and roofing workers (n=67). Two mobile phones were used for the task (Figure 4b), and the grid was added to jobsite layout on the Ajou app (Figure 4c).

Step 3: Data visualization

Data visualization could be achieved in two ways: directly within the Ajour app or by exporting data as a .CSV file for more in-depth analysis. Within the app, it is possible to filter data by trade, work category, or work breakdown. However, the app's capabilities were limited, as it did not support charts or complex graphics but only filtered observations displayed on a map. For more advanced analysis, data was exported to MS Excel, where the tools scatter plots, pivot tables, VB scripts, and slicers were used to visualize worker locations.

Step 4: Data analysis

Microsoft Excel was the primary tool utilized for data processing and visualization for conducting three types of analysis: (1) Spatial-time; (2) heat map; and (3) interference.

i. **Spatial-time analysis**: This approach examined how tasks and activities were distributed over time and space, revealing patterns in workflow and resource allocation.

ii. **Heat map analysis**: Heat maps were employed to identify areas of concentrated activity or inefficiency, offering a visual representation of site dynamics.

iii. **Interference analysis**: This method identified specific disruptions or inefficiencies in workflows, enabling researchers to diagnose the root causes of delays or productivity losses.

The data characteristics mainly influenced the reasons for conducting those kinds of analyses, as each random observation contained the following information: (1) time stamp; (2) trade observed; (3) work category; (4) workspace category; and (5) coordinates. The three kinds of analyses ensured a comprehensive understanding of the data characteristics.

RESULTS

The overview of the observations helps to identify where each trade is located. Figure 5 displays how the activities are being dispersed in the site by all trades; it shows a glimpse of the site dynamics. The tool allows observers to view the overall site activity (Figure 5a) and individual trade performance (Figure 5b). Attention can be directed to areas with multiple trades working nearby (Figure 5b), where space may be a constraint. Additionally, Figure 5c illustrates time allocation across the site by all trades, helping to distinguish between value-adding (green dots) and non-value-adding activities (red dots).

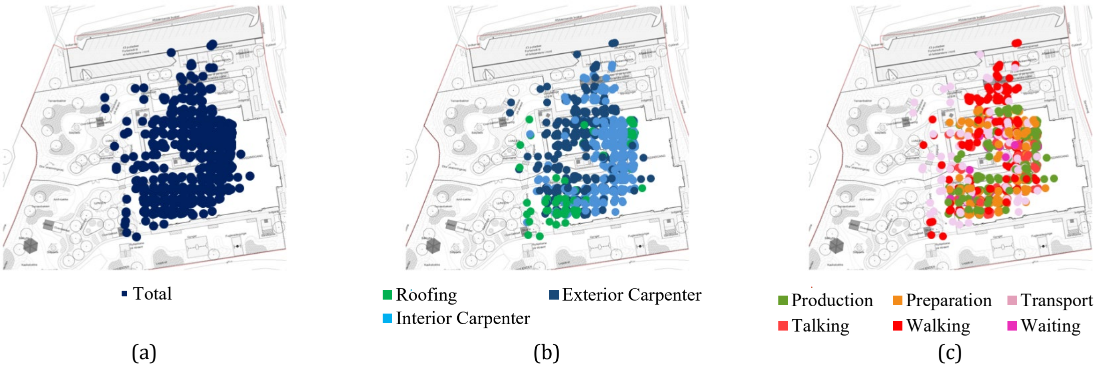


Figure 5: Overview of the data: (a) Total observation; (b) By Trade; and (c) By work activity

USE 1: SPATIAL-TIME ANALYSIS.

Figure 6 shows a combination of the visual distribution of the observation on the jobsite (Figure 6a-1 to Figure 6c-1; it means the first row of Figure 6); the distribution of time into workspaces (Figure 6a-2 to Figure 6c-2); and the distribution of time into workspaces (Figure 6a-3 to Figure 6c-3). This type of analysis helps to identify "where" and "how" the workers spend their working time. For example, the spatial-time analysis of the external carpenters revealed that they are the trade who spend less time in production activities (28%, Figure 6b-3) and the most significant quantity of time walking (20%, Figure 6b-3); these results can also be justified with the results of the distribution of time into workspaces. They spent 42% of their time (Figure 6b-2) on transportation workspaces and 25% on preparation and storage workspaces (Figure 6b-1). Those numbers reveal excessive time spent on movement and transportation activities. If a worker makes frequent movements between workstations, it may indicate an inefficient site layout. Consequently, it can cause a delay in task completion.

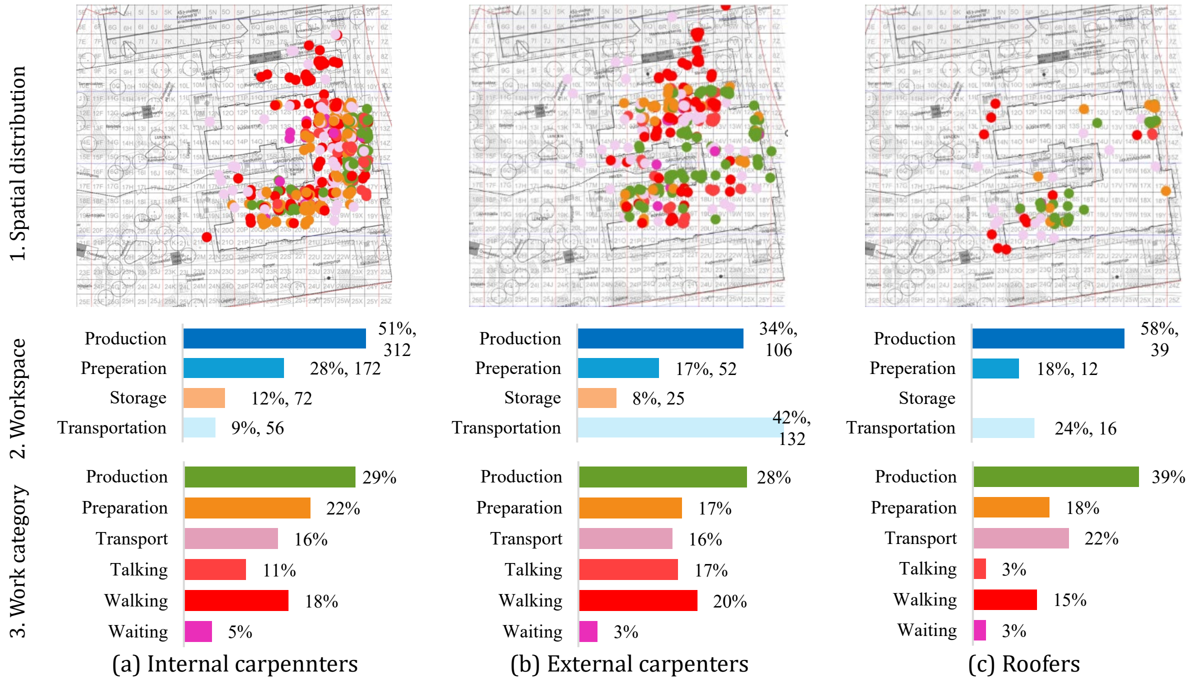


Figure 6: Spatial-time analysis: (a) Interior carpenters; (b) Exterior carpenters; and (c) Roofers by 1. Spatial distribution; 2. Time by workspace; and 3. Time by work category

USE 2: HEAT MAP ANALYSIS.

The heat maps (Figure 7) served as a valuable tool for qualitatively assessing the amount of time workers spent in different locations. This analysis assumes that an optimal project workflow enables trades to focus primarily on value-added tasks. When workers spend more time in a workspace, the frequency of observations increases. Therefore, heat maps visualize observation intensity, indirectly indicating the time a worker spends at a specific location.

In this way, the heat map analysis can help to interpret what is happening on the jobsite, visualizing areas of high and low activity. In the case of the study, the heat map allowed us to visualize the exterior carpenters (Figure 7a-2 to Figure 7d-2) frequently moving between different areas rather than staying in one place for a focused task. This could be for several reasons: (1) poor workspace optimization, (b) congested spaces, and (c) unclear task assignments.

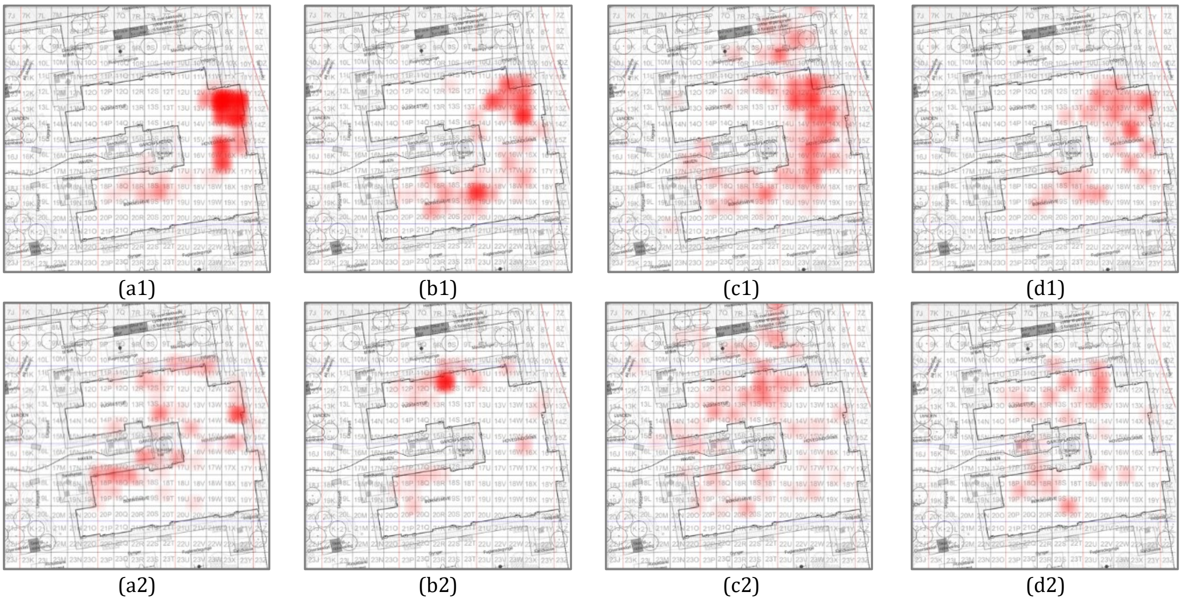


Figure 7: Heat map: (a) production; (b) preparation; (c) walking & transportation; and (d) Waiting & talking by 1. Interior carpenters; and 2. Exterior carpenters

USE 3: INTERFERENCE AND CONGESTION ANALYSIS.

This analysis focused on identifying areas of congestion and how it has affected the workflow on the construction site, focusing on locations with multiple trades working simultaneously or several workers of the same trade in a confined space. During the application, exterior and interior carpenters rarely shared production workspaces, resulting in minimal interference between the trades. Nevertheless, it was observed that several interior carpenters (about 5 to 7 workers) were working within the same reduced area (approx. 30m²) to perform their production activities in shared preparation workspaces close by. The distribution of activities in production and preparation workspaces was analyzed to assess the impact of interference and obstructions within the same trade (Figure 8).

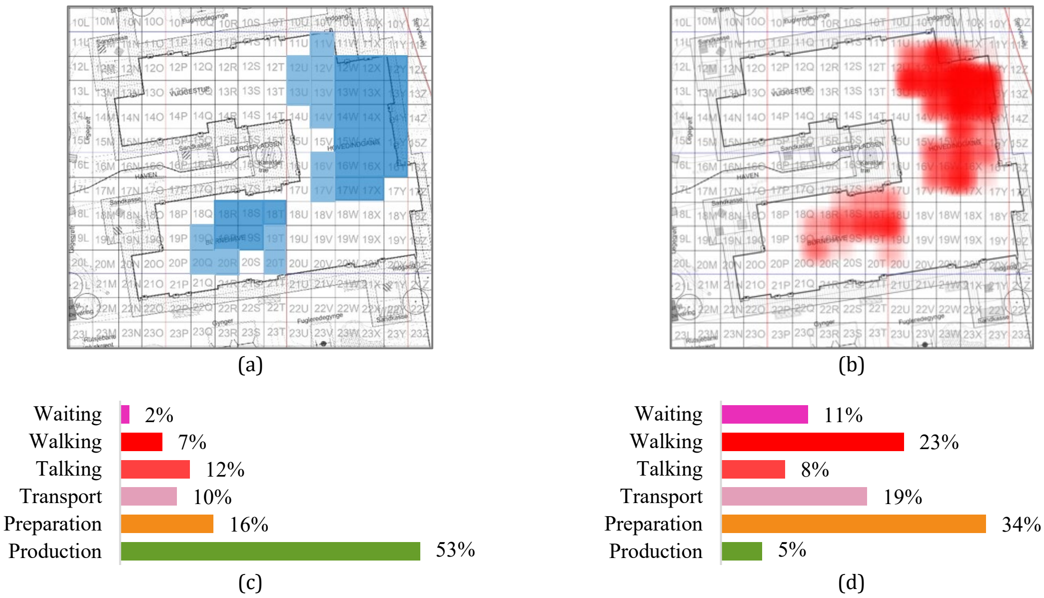


Figure 8: Congestion analysis of internal carpenters (a) Prod. and Prep. Workspaces; and (b) Heat map analysis; (c) Activity distribution in Product.; and (d) Activity distribution in Prep.

Observations within production workspaces indicated that only 53% of the activities involved actual production tasks (Figure 8c). Additionally, 16% of the functions were minor preparation activities conducted within the production area, further reducing efficiency. Non-productive activities, such as talking (12%), transporting (10%), and walking (7%), occupied a significant proportion of time. Information obtained during non-structured interviews with the workers highlighted the inefficiencies caused by overcrowding and a lack of task delegation, particularly in areas where production should ideally dominate.

When preparation spaces were analyzed, the activity distribution revealed significant inefficiencies. For example, waiting accounted for 11% of the observations while walking (23%) and transportation (19%) emerged as major contributors to time usage (Figure 8d). Moreover, information obtained during non-structured interviews with the workers confirmed that workers often had to wait in shared preparation spaces until others finished their tasks. Additionally, workers frequently needed to relocate to distantly situated preparation areas due to overcrowding, further worsening inefficiencies.

CONCLUSIONS

This study addresses the research question regarding how the traditional work sampling technique, combined with spatial location data, named location-based work sampling, could be utilized to identify workflow issues. To achieve this, a case study was conducted on a Danish new building project, and the workflows of three trades were observed, leading to the identification of three potential uses of the tool for identifying workflow issues. The location-based work sampling application presented a structured four-step methodology: (1) activity and workspace identification; (2) data collection; (3) data visualization; and (4) data analysis.

This study's primary contribution is revealing location-based work sampling as a robust tool that could smooth the project workflow by allowing users to identify, analyze, and address workflow issues. It provides insights into three areas. Firstly, work activity-specific analysis to qualitatively assess how much time workers spend on value-added versus non-value-added activities; and identifying excessive walking and waiting times. Secondly, heat maps for workspace and resource utilization, assist in evaluating how labor and materials are distributed across the site. Lastly, interferences and congestion, detecting areas where workflow slows down due to overcrowding or mismanagement.

A second contribution of this study is the introduction of two key modifications to the location-based work sampling technique, enhancing its previous application. Firstly, a mobile app facilitates the registration of observations, improving data collection efficiency and accuracy. Secondly, a flexible grid for workspace identification, implementing a grid system allows for adaptable workspace categorization, accommodating changes in project phases and trade-specific requirements. These modifications enhance the scalability and applicability of the technique, making it more adaptable to dynamic construction environments.

Several areas for further research have been identified to enhance the effectiveness and adaptability of the location-based work sampling tool. A promising avenue is the development of time-integrated heat maps to visualize worker activity patterns over extended periods. This approach could illuminate temporal trends and assist in understanding how workspaces are utilized dynamically. Additionally, refining congestion analysis by incorporating time thresholds would allow for more precise identification of congestion levels, enabling the establishment of realistic benchmarks for spatial utilization aligned with project schedules. Finally, further research should explore how location-based work sampling results can be integrated into other Lean methods, as well as daily managerial routines and processes.

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