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LOCATION-BASED WORK SAMPLING

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ABSTRACT

Previous studies have applied the Work Sampling (WS) technique in different job sites to determine how workers employ their time in relation to a taxonomy of various work activities. However, no other significant contribution has been discussed for including location information of the work activities. This study added a geographic location to each random WS observation for a more comprehensive work efficiency analysis. In this paper, an implementation analysis was presented based on the findings from a case study. The research process followed four steps: (1) clarifying the categories of the activities; (2) deciding the confidence interval; (3) collecting and extracting data; and (4) analyzing the data. For adding location data to the technique, the authors used the geographic coordinates provided by smartwatches used by the research team connected to two Global Navigations Satellite Systems (GNSS), and the coordinates obtained from photos taken for each observation. Each observation made contained the following information: (1) photo; (2) timestamp; (3) trade observed; (4) work category; and (5) geographic coordinates, consequently, workspace category. This paper presents as the main contribution an adaption of the WS technique, named Location-based Work Sampling (LBWS), which can provide a better understanding of the ongoing activities' behavior.

KEYWORDS

Location-based Management (LBM), Visual Management, Waste, Work Sampling, Geographic location observations.

INTRODUCTION

The time study technique popularized under the name of Work Sampling (WS), which is deployed to determine how workers spend their time on different work activities, became popular, among other reasons, due to its easy and straightforward application. The theory of WS is based on the laws of probability, which indicate that observations made at repeated random times will have the same distribution. Thus, random observations can be translated into percentages of time spent in activity categories (Barnes, 1968).

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Over the years, the technique has been employed by Lean practitioners and researchers for several different purposes: (a) to provide insight for comparing the average productive workforce utilization to respective work processes in various projects (Picard, 2002); (b) to measure labor efficiency and inefficiency (Neve et al., 2021; Ramaswamy, 2009); (c) to measure and conceptualize flow and workflow (Kalsaas, 2011; Wernicke et al., 2017); (d) to identify the share of time spent on a single activity of the same construction process on different job sites, e.g., transportation (Pérez et al., 2015); (e) to set up a baseline measure for improvement and to serve as a challenge to management and the workers (Neve & Wandahl, 2018); (f) to understand the evolution of share of time spent in different work categories along the years (Wandahl et al., 2021), among others.

In most cases, the researchers and practitioners focused on understanding the share of time spent in the different work categories without explicit attention to the location where those consuming time activities were being conducted; and when identifying the observation locations, the observers generally divided the site into observation zones. An example of this was presented in the study of Wernicke et al. (2017). The authors categorized the observation made on an off-site production system regarding the following work areas: floor line, assembly line, and safety line. However, the difficulty arises because of the fundamental difference between the work zones of a manufacturing plant, as opposed to a construction site; the work activities do not change through the locations.

Hence, previous studies provide little insight about causative factors about the distribution of the share of time through the job site locations. Thus, this research aims to fill the knowledge gap regarding how to use the WS technique to provide information for identifying where the work activities identified were observed. This research supports the idea that the adaptation of the WS technique combined with among other Location-Based Management Systems (LBMS) can be considered decision support systems. Hence, this exploratory case study was driven by the following question:

- Which opportunities can merging geographic location data with Work Sampling data bring for construction management?

An exploratory case study of a building renovation project was deployed to address this question. This paper differs from others WS studies in its practical focus: this is a study using actual data for understanding the utility of geographically located observations (geo-located observations for short) collected during the WS application to improve project control and site efficiency. This is an ongoing research project, so the utility of this new WS adaptation was not yet fully evaluated. Therefore, the discussion of the results is mainly descriptive.

RESEARCH METHODOLOGY

This research deployed a case study (Yin, 2003) as a primary research strategy, as case studies offer flexibility for explorative and theory-building research in real-life contexts. During the case study, the research scope can be re-addressed and complementary data sources can be acquired, while the method also serves several types of research objectives (Beach et al., 2001). Among the number of options in carrying out case research, the authors characterize this study as an exploratory case study.

This case study is part of a research project aiming to improve productivity in the Danish construction sector by adopting Lean tools, techniques, and methods. The main actors of the research project are: (1) a consultant firm; (2) a research team represented by the authors of this paper, and (3) three Danish medium and large-sized contractors (named in this research as Organization A, B, and C). The consultant firm is responsible for the Lean implementation. The research team aims to establish the construction project efficiency baseline before and after the Lean adoption. For that, the authors gathered data using several sources of information and techniques. This paper focuses on the data collected through the WS application in a job site of Organization A. The construction company provided access to project-related documents, observation of routine activities, and interaction with team members to learn about the processes on site.

The case organization of the present paper (Organization A) is one of the main contractors in the building sector in Denmark. The case study was conducted on a building renovation project in Roskilde during weeks 45 and 46 of 2021. The construction project consists of renovating 24 five-story housing buildings. The project presented several milestone phases. Four buildings of phase 1 were under renovation during the period of this case study, named Building A1, B1, C1, and B2 (see Figure 1).

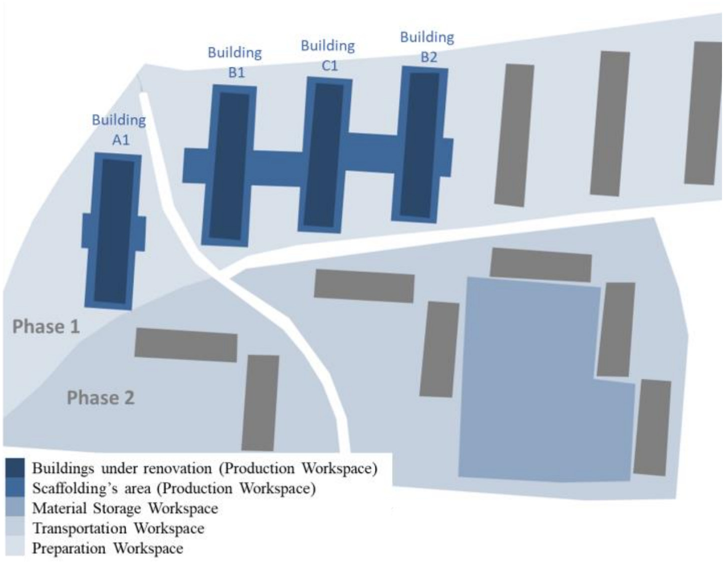

Figure 1: Job site layout.

Figure 2: Façade scaffolding and scaffolding between Buildings B1 and C1.

The main renovation tasks were applied from outside-in and related to mainly carpentry work, such as replacing windows and roofs. Installing new ventilation and electricity systems represented the only two inside renovation activities. During the execution of the renovation project, tenants are granted rehousing in the period when their apartment is being renovated, but they are living in the apartment during the remaining renovation. For this reason, most of the renovation activities were conducted outside the buildings from a façade scaffolding (Figure 2). Moreover, from the referred scaffolding, workers completed masonry and painting work.

Organization A placed modular containers within the job site for storage, administration, and changing rooms (named as Material Storage Workspace in Figure 1). The main material storage area, destined for inventory deliveries, is located next to the administrative containers. Several camp tents were installed at ground level next to the buildings under construction for conducting support activities, such as painting wood panels before installation, cutting steel profiles, cutting wood panels, etc. Organization A rented a façade scaffolding with plastic covering the entire temporary structure for each building under renovation. The scaffolding of Buildings B1, B2, and C1 are interconnected to facilitate workers' movement among the buildings, as illustrated in

Figure 2. The scaffoldings included a cabin as the main lift solution (see the lift in Figure 2) for material transport. Moreover, a mobile crane was used for lifting windows using hooks for installation and pallet lifts for transportation.

RESEARCH DESIGN

The research process followed these steps: (1) to clarify the categories of the work activities and workspaces; (2) to decide the confidence interval and the accuracy desired; (3) to collect and extract data; and (4) to analyze the data.

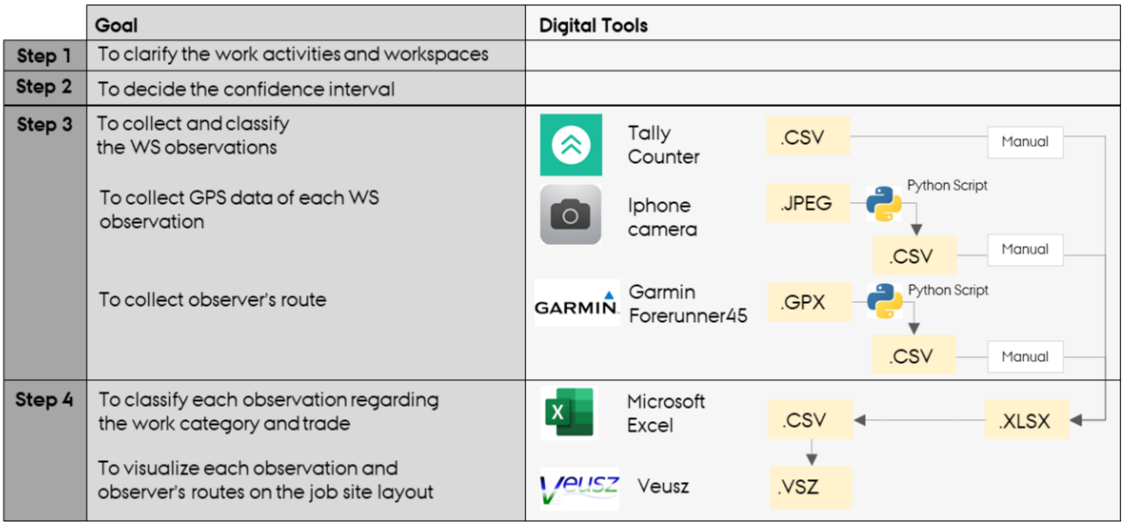

Figure 3: Research design.

Step 1: Clarifying the work activities and workspaces

The authors classified the activities of each trade observed on the job site during the first day of job site visits, named as Day 0. In this study, a six-work categories classification was adopted to keep consistent with previous WS studies carried out by the research team as part of a long-term research project. The six categories are: (1) production, e.g., installing gypsum boards; (2) talking, e.g., discussing the installation process; (3) preparation, e.g., measuring with a ruler; (4) transportation, e.g., carrying tools; (5) walking, e.g., moving empty-handed; and (6) waiting, e.g., delaying action until receiving material. Regarding the job site locations, this study adopted the following workspace classification: (1) production workspace, this being the buildings under renovation and the scaffolding area; (2) preparation workspace, represented by the area of the scheduling phase 1 excluding the production workspace; (3) material storage workspace, consisting of the container's area; and (4) transportation workspace, considering the area between phase 1 and the material storage area. The job site division into workspaces is seen in Figure 1.

The scope of the observations was limited to the trades that conducted their activities outdoors during the period of visits. So, the WS technique was applied in seven trades including a total of 40 workers (representing a sample of N=40) from Day 1 to Day 7: (1) carpenters (N_1=13, representing 32.5% of the workers); (2) masons (N_2=5, 12.5%); (3) electricians (N_3=4, 10%); (4) ventilation (N_4=6, 15%); (5) scaffolders (N_5=2, 5%); (6) painters (N_6=4, 10%); and (7) demolish trade (N_7=6, 15%).

Step 2: Deciding the confidence interval and the accuracy desired

The data collection period lasted seven days (8.5 hours/each) from 07:00 to 15:30, excluding breaks: coffee break (09:00 to 09:15), lunch break (11:30 to 12:00), and coffee break (13:30 to 13:45). The research team made the observations from the scaffolding (from the façade and roof level) as interior tours were not possible due to the presence of the tenants. Figure 4 presents the distribution of the observations through the working hours, and Figure 5 illustrates the number of observations on each of the seven days of data collection. The blank space represents the lunch break. The random tours, conducted from Day 1 to Day 7, aimed to avoid observing patterns of behavior. Hence, the observers varied both their routes through the job site and, to increase randomness, the times for observations. According to CII (2010), the required number of observations per hour is 46 for a site with 0-50 workers. Thus, for workdays with 7.5 hours of working time, a minimum of 345 observations were required, i.e., ≈ 50 observations per day. After completing seven days of data collection, 993 geo-located samples were recorded with a 95% confidence interval of ± 2%.

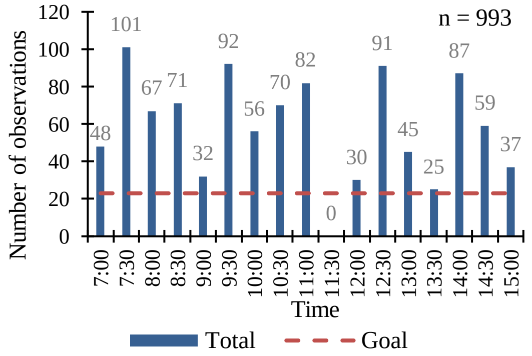

Figure 4:Total number of observations distributed along the workday.

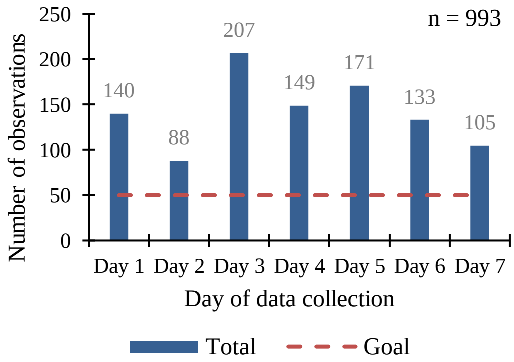

Figure 5: Total number of observations on the 7 days of data collection.

Step 3: Collecting and extracting the data

The research team used several digital devices to collect data during the random tours. A tablet was employed for separating the observations according to the six-work categories classification using the application "Counter – Tally Counter" by Tevfik Yucek (Apple, n.d.). A tally counter is a digital number clicker used to count something incrementally. The Counter application allowed the researchers to digitally record each observation with an exact time and export this data in a Comma-Separated-Values (CSV) format.

A mobile phone was used for taking pictures of each observation. At no time were individuals' faces or other identifiers registered; the purpose of the photo was to collect the geographic coordinates from each observation. The authors extracted each observation's location and additional metadata (timestamp and file name) stored using the Exchangeable Image File Format (EXIF) Phyton library. EXIF is a standard that specifies the formats for images for recording technical details associated with digital photography (EXIF.org, n.d.).

A smartwatch, specifically a Garmin Forerunner45, was worn for tracking the path conducted during random tours. This device allowed to identify the location where each observation was made, and the zones observed during the tours. This device provided the geographic coordinates using a combination of two Global Navigations Satellite Systems (GNSS), those being: The Global Positioning System (GPS) and the GLONASS GNSS.

The smartwatch data was synchronized to the laptop Garmin application using a USB cable. The activity saved during the 8-hour tours was exported in a GPS Exchange Format (GPX), then transformed into a CSV using phyton programming. Thus, each geo-located observation contained the following associated information: (1) photo; (2) timestamp; (3) trade observed; (4) work category; and (5) geographic coordinates, consequently, workspace category.

Step 4: Analyzing the data

The analysis aimed to resolve the research question For this, the data extracted from the devices during the random tours was visualized using the Veusz program. Veusz is a free scientific plotting and graphing program for producing 2D and 3D plots (Veusz, n.d.). This allowed the researchers to plot each geo-located observation using a graphical 2D user interface. Not only the observations collected were imported from the CSV files, but also the path conducted by the observes during the WS application. The authors collected the coordinates of the job site facilities and buildings using the smartwatch, and converted them to a visual layout using the RouteConverter program. RouteConverter is a free, GPS tool to display, edit, and convert routes from several different file formats (RouteConverter, n.d.). The list of job site coordinates was exported into a Microsoft Excel Open XML Spreadsheet (XLSX), converted into a CSV format, and then imported to Veusz. Hence, Veusz allowed visualizing the position of each observation on the job site layout. In this study, the analysis aimed to identify how and where the workers spent their time.

RESULTS AND DISCUSSION

Figure 6a presents, using black dots, the location where each geo-located observation (n=993) was made during the WS application. Moreover, light grey dots represent each of the locations of the path where the observers conducted the random tours. From the images represented in Figure 6a, it can be observed that the locations of the observations are mainly distributed in Building A1, B1, B2, and C1 as expected, and, in some cases, observations were made in the material storage area.

In Figure 6b, the observations are marked with distinct colors according to the trade they represent (blue for carpenters, brown for masons, dark grey for electricians, yellow for ventilation workers, blue for scaffolders, green for painters, and red for demolition trade). In this way, it is possible to create a subdivision of each geo-located observation into trades which can provide a detailed view of where each task is being conducted.

For example, taking a closer look at Day 4 (Figure 6b), 149 observations were made on this day. 82 of these, or 55%, were of the carpenter crew (blue dots). They were mainly observed on Building A1 and B1, and in the material storage workspace and preparation workspace by the offices. Masons were observed 21 times, corresponding to 14% of the total number of observations on Day 4. The masons were mainly observed on building C1 and in the area between buildings. The electricians (dark grey dots) were only observed 2 times on this day, both in the material workspace, representing 1% of observations. The distribution for the remaining 4 trades is as follows: 10 observations of ventilation workers (yellow dots), 17 observations of the scaffolding crew (blue dots), 8 observations of painters (green dots), and 9 observations of the demolition trade (red dots), corresponding to 7%, 11%, 5%, and 6% of the total number of observations for Day 4, respectively.

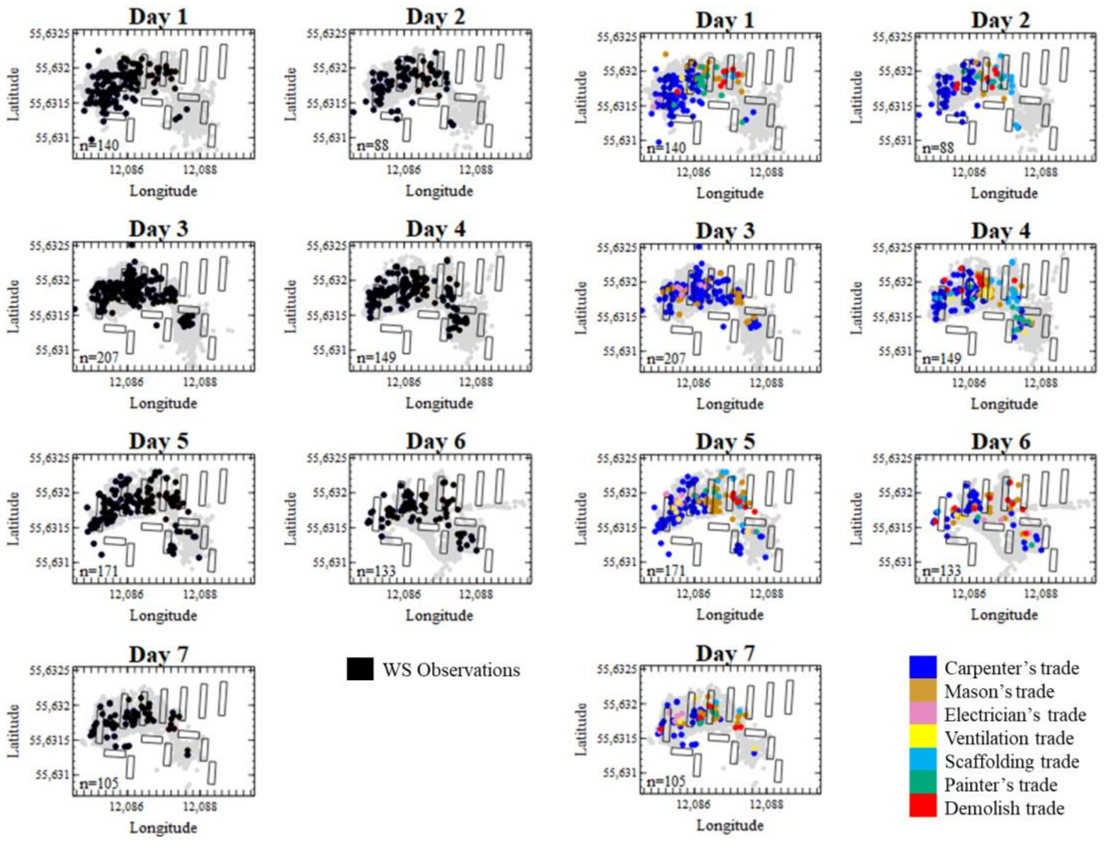

Figure 6: (a) Location of each observation; (b) Trade classification of each observation.

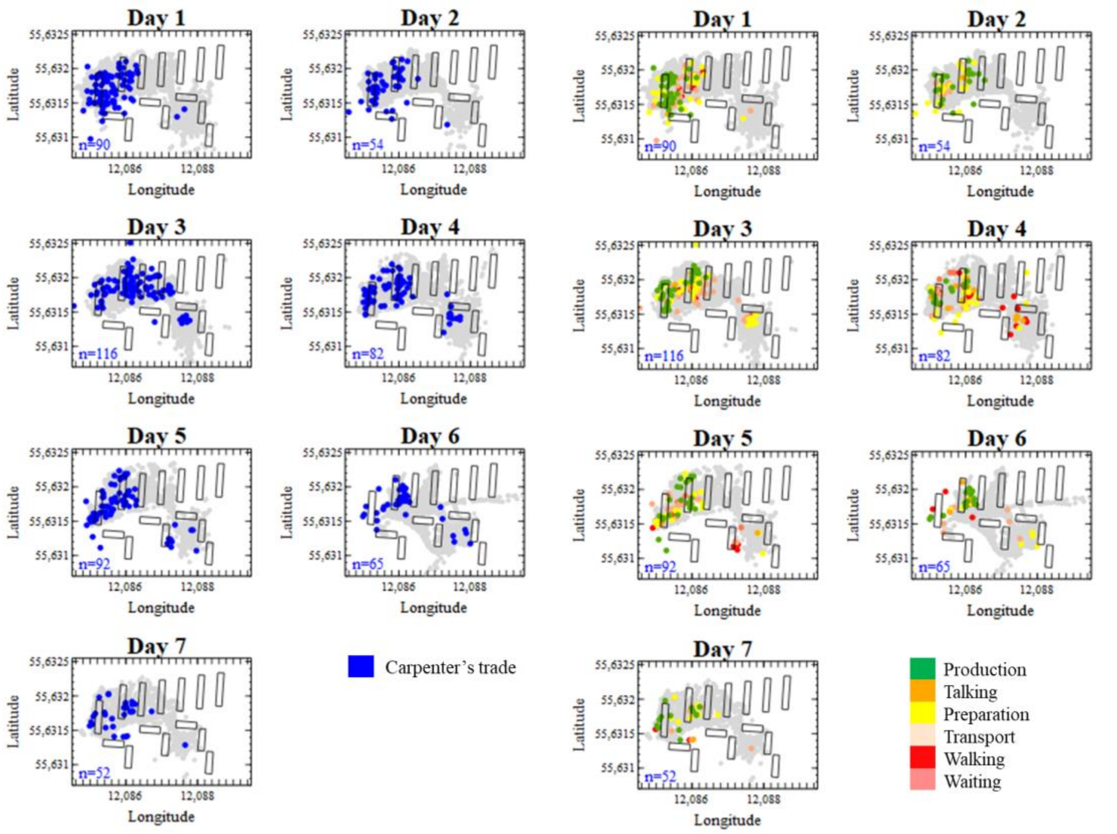

Figure 7: (a) WS on carpenters trade; (b) Position of carpenters' WS categories.

Using this 2D representation to see where on the job site construction workers are located can be used during planning meetings with contractors to see where the potential problems are, thus forming the starting point for discussion. This way, objective data presented in visual form can be a joint base for learning. By discussing the change in position during a week, each trade can explain to the others what causes position changes in their workflow, and this way, all trades obtain a greater overview of the renovation process. So, those illustrations can allow trade supervisors and managers to solve minor flow problems and coordinate details in their work schedules, thus preventing minor issues growing bigger.

The analysis of the distribution of the time of each trade can also be conducted. Figure 7 presents the distribution of the observations made on the 13 workers of the carpenter trade. In Figure 7a, all observations are shown in the same color, which gives an initial overview of the location of the observations. In Figure 7b, the observations are colored according to their work category. The total number of observations on the carpenter trade (n=574) are distributed with 28% on production, 7% on talking, 30% on preparation, 22% on transportation, 10% on walking, and 3% on waiting. Figure 7b shows that production tasks generally take place in and around buildings A1, B1, and C1. Preparatory tasks also take place here, but they are also observed in the material storage area, where a dedicated preparation workshop was set up. Waste work observations (walking and waiting categories) are scattered throughout the site.

Looking more closely at one of the data collection days, it is possible to elaborate further on the Location-Based Work Sampling (LBWS) results. An example of the Distribution of Observations (DO) collected on a single day, Day 4, can be seen in Figure 8. With these illustrations, the share of time spent in each work category and in each workspace can be analyzed from several different perspectives.

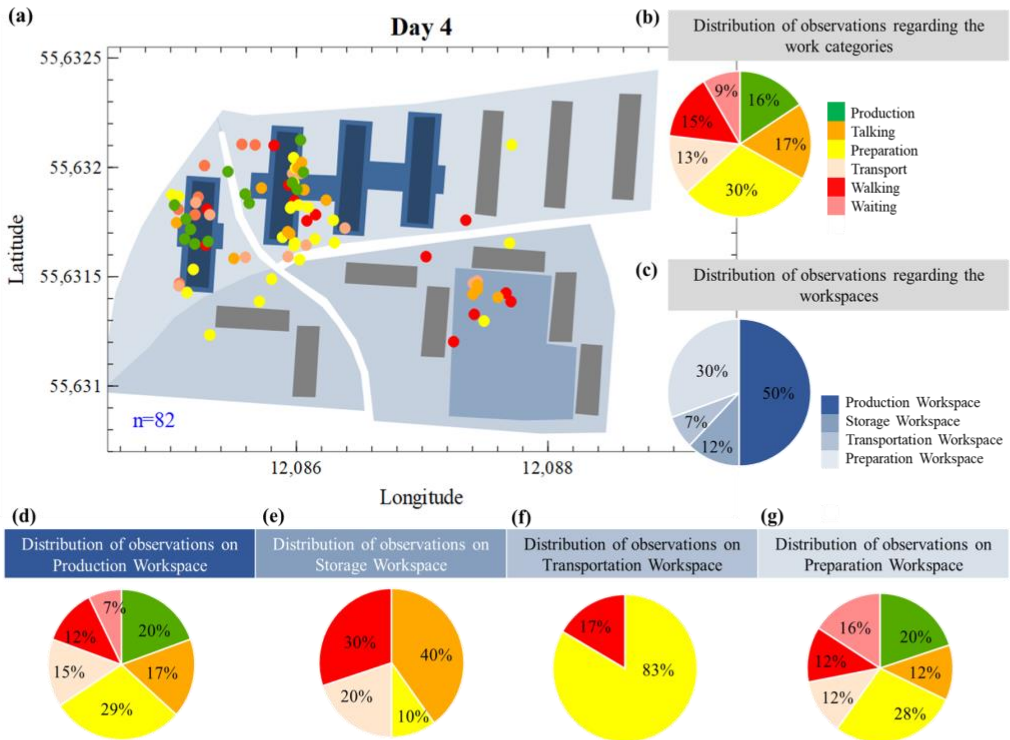

Figure 8: (a) WS on carpenter trade taken on Day 4; (b) DO regarding the WC; (c) DO on workspaces; (d) DO on Production Workspace; (e) DO on Storage Workspace; (f) DO on Transportation Workspace; and (g) DO on Preparation Workspace.

Firstly, Figure 8b gives a general insight into which work category carpenters spent most of their working time on. It can be seen that almost one-third of the carpenters' time on Day 4 was spent on preparation tasks, which is close to twice the amount of time that was spent on direct work. Secondly, the time spent by carpenters in the production workspace was the same as in the other three workspaces combined (Figure 8c). The carpenter trade had 41 samples recorded in the production workspace, equaling 50%. As this workspace is surrounding all the buildings undergoing renovation, the amount of time spent in this area represents, among other things, carpenters moving from one building to another, preparing windows, which are stored in this area, and preparing materials.

The third perspective illustrates the distribution of work categories observed in each workspace, illustrated in Figure 8d, e, f, and g. Although 50% of samples recorded on Day 4 (Figure 8c) were observed in the production workspace, only 20% of these observations showed the carpenters being productive in this area (Figure 8d). The carpenters spent most of their time in the production workspace on preparation activities, corresponding to 29% of the observations (Figure 8d). A plausible explanation of this is the nature of the roof renovation process, which involves a lot of measuring and cutting activities before the installation of roof materials can take place. The roof is a large area, and the limited number of cutting stations and dedicated material storage areas explain the relatively large share of observations made on walking and transportation in this workspace (i.e., 27%, Figure 8d).

In the storage workspace, 40% of the observations are talking, 10% are preparation, 20% are transportation, and the remaining 30% are walking (Figure 8e). There are two reasons for this distribution: firstly, this workspace is also where the changing rooms and breakrooms are placed, so it is here the carpenters start and end their workday, and where they come back to have their lunch break in the middle of the day. Naturally, this leads to much of the time in this area being spent on walking and talking. Secondly, besides the preparation workshop mentioned earlier, the storage workspace contains all the workers' tool containers. This explains the 30% of observations on preparation and transportation combined.

The transportation workspace is where the smallest number of observations were collected, only representing 7% of the total number of observations on Day 4 (Figure 8c). Here, only preparation (83%) and walking (17%) were observed (Figure 8f). This workspace is placed between the production and preparation workspaces and the storage workspace, which explains the share of walking observed here. The distribution of work categories observed in the preparation workspace is shown in

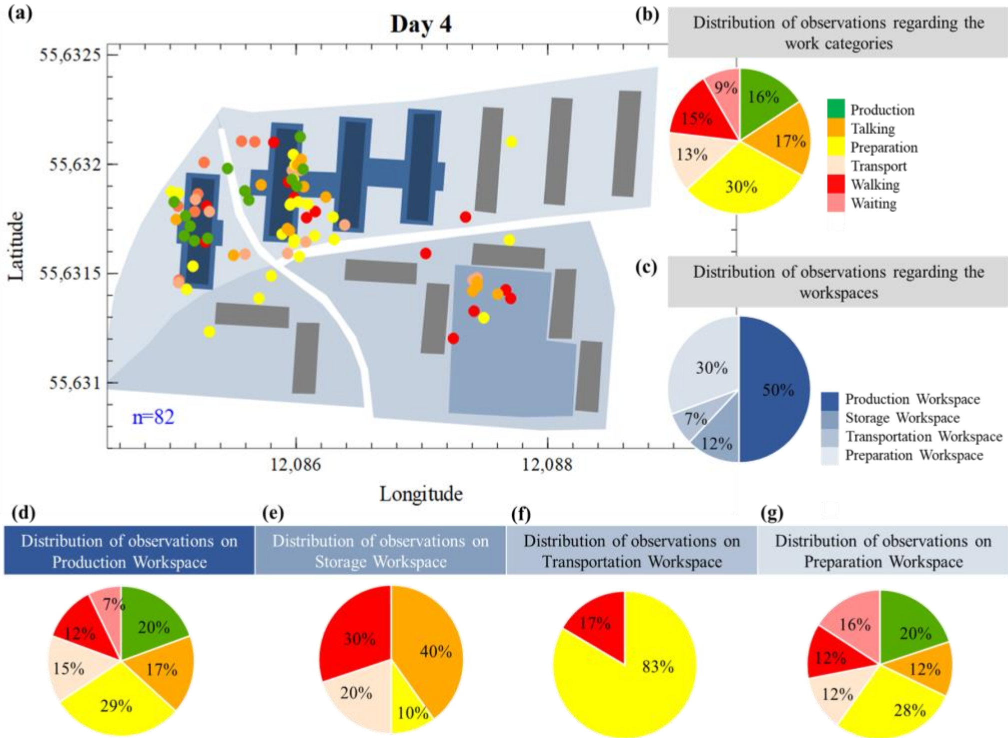

Figure 8g. As expected, most of the carpenters' time in this workspace is dedicated to preparation activities, representing 28% of the observations. The remaining 78% of observations are distributed very similarly to the distribution in the production workspace due to the diversity of tasks carried out in this area, as described in the paragraph above concerning Figure 8c.

The main contribution of this new WS adaptation is related to the implementation of some core Lean principles: (1) use visual management; and (2) process transparency. Firstly, the adoption of LBWS could enable the adoption of visual management tools to identify where the activities are conducted by using color-coding to place trades. Moreover, LBWS will support identifying where productive, preparatory, and waste activities happen. LBWS supports identifying the working areas where most waste happens as many potential problems quickly become evident.

Secondly, process transparency can be achieved through the simple representation of trade location on the job site. LBWS used for representing where activities are being conducted can enable an effective communication of the project to the stakeholders. The level of detail of the LBWS depends on the level of control of the job site manager. The division of the WS work categories into smaller tasks according to the same level as the Work Breakdown Structure (WBS) can be a useful tool to visualize and manage the project. However, decomposition into all work activities can make the WS application very intricate and time-consuming. The time it takes willbe disproportionate compared to the benefits. The same example can be used for the division of workspaces. As every project is different, the right workspace decomposition for the LBWS is the one that best fits the Location-Breakdown Structure (LBS) used by the job site manager.

Lastly, based on the presented discussion, the authors define LBWS as a visual graphical approach that facilitates sharing information obtained during the WS application, based on adding geographic location information to the random observations.

The visual technique shows the observations made on construction trades and work categories in the foreground and job site spaces in the background.

CONCLUSION

The application of the WS technique on construction sites has, in general, been limited to the understanding of how workers spend their time regarding work categories. For a more comprehensive work analysis, this study aimed to identify which opportunities adding geographic information to the random observations made (named in this study as geo-located observations) can bring. To address this, the authors presented the implementation of a novel adaptation of the WS technique, named Location-Based Work Sampling (LBWS), based on the findings from a case study conducted on the job site of a large contractor in Denmark. LBWS was used to visualize how and where seven trades spent their time during seven days of data collection in a renovation project.

Creating a relatively simple visualization of the observations on the job site layout showed that a more comprehensive analysis of the job site activities could be conducted. Many research opportunities arise from this exploratory case study. Geographic location observations will be helpful in the implementation of the Lean principles of "use visual management" and "process transparency". The association of the geographic position of each observation with the scheduled activities can be further investigated. The new adaptation of the WS technique can provide a better understanding of the ongoing activities' behavior and contribute to the existing Location-Based Management Systems.

However, several limitations were identified for the adoption of LBWS. The main limitation relates to the use of geographic coordinates provided by the photos taken with smartphones and smartwatches, which are mainly ideal for outdoor locations. Thus, limiting the application of this technique to construction activities carried out outdoor. In future studies, the research team will test other technologies for indoor geo-location when activities are observed inside the buildings under renovation. Moreover, other kinds of tools will be tested to add location information to the WS observations. Another significant limitation is related to the data collection process on the job site. Data collection is a very time-consuming activity. To overcome this limitation, automated methods for data collection can be implemented in future steps. The present researchers will test the adoption of location-tracking sensors (e.g., GNSS) embedded into wearable devices for collecting workers' positions and activity recognition. Lastly, the results are mainly descriptive because of the small amount of data collected in one single case at this stage of the ongoing research project.

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