Pérez, C. T., Salling, S. T. & Wandahl, S. (2023). Location-based work sampling: field testing and utility evaluation. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31)*, 1160–1171. doi.org/10.24928/2023/0131

LOCATION-BASED WORK SAMPLING: FIELD TESTING AND UTILITY EVALUATION

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ABSTRACT

Visual management has been developed and used by Lean practitioners to enhance communication and control operations and processes. Lean construction, as a process-focused approach, and emerging IT tools have the potential to transform and facilitate construction operations. The authors of this paper have previously presented a prototype adaption of the work sampling technique, called location-based work sampling, based on the results of a case study. However, the utility of this visual management tool has not yet been tested. Thus, this research aims to assess how the tool can provide managers with helpful information for decision-making. The paper presents the second learning cycle of a research project that adopted the Design Science Research strategy. The second cycle includes five steps. The first four steps consist of the application of LBWS, and the last step represents the evaluation: (1) clarifying work activities & workspaces; (2) data collection; (3) data visualization; (4) data analysis; (5) tool evaluation. The assessment results show that the tool, to a high degree, fulfills the six requirements of a digital visual management practice. However, the assessment also concludes that further development is needed to fully understand user needs and integrate the tool into daily management routines and processes.

KEYWORDS

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

INTRODUCTION

Visual Management (VM) can be defined as a set of practices that support visual communication by adopting different visual devices (Tezel et al., 2016). Lean practitioners have developed and used VM and its tools to enhance communication and control operations and processes in real time (Parry & Turner, 2006). Among the benefits of VM is that it directly supports other management efforts, such as production management, safety management, performance management, and workplace management (Tezel et al., 2016). Moreover, the use of VM tools reduces feedback time for action taking (Alvarez & Antunes Jr., 2001). Tezel et al. (2015) have investigated the advantages of VM as a managerial strategy that can benefit a project in aspects such as transparency, ease of information flow, and minimizing complications in communication.

Although VM tools have been used in the construction industry for a while as signs, color coding, and hazard elements, there is a significant potential for implementation at managerial levels in combination with Information Communication Technologies (ICT) (Tezel et al.,

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2016). Some researchers have integrated IT and tools with VM to improve efficiency and communication in construction projects. Some examples of these approaches are: (1) Integration with Building Information Modeling (BIM), named KanBIM (Sacks et al., 2009); (2) Integration with BIM-based sheet (Matta et al., 2018); (3) Digital Last Planner System (Conte et al., 2022; McHugh et al., 2022; Pikas et al., 2022); (4) Visual Management to support design planning and control (Pedó et al., 2022); and (5) Construction progress monitoring (Álvares & Costa, 2019).

Some of those VM tools have been converted into successful IT-based prototypes. In the prototypes, information visualization interfaces (often BIM models) are displayed on large touch-screens in the field and supported by a Lean construction engine (e.g., a virtual Kanban system linked to the Last Planner System by Ballard (2000)) connected to the existing main-servers and Enterprise resource planning (ERP) systems. Although useful, those prototypes do not fully illustrate the extensive potential of the combined use of Lean construction techniques and emerging IT systems (Tezel & Aziz, 2017).

As a new approach, “the present authors” (year) adapted the traditional Work Sampling (WS) technique by adding geographic information collected using mobile computing to the random observation, creating the VM tool named Location-based Work Sampling (LBWS).

“The authors” (year) defined 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, named geo-located observations. The visual technique shows the observations made on construction trades and work categories in the foreground and job site spaces in the background.

The authors of this paper previously presented the prototype adaptation of the WS technique based on the results of a case study. However, the utility of this VM tool using IT has not yet been tested. Thus, this paper aims to assess how the tool can provide job site managers with useful information for decision-making. This is an ongoing research project, so the evaluation of this new WS adaptation was exclusively performed after the field testing in one construction project.

RESEARCH METHODOLOGY

The present authors adopted the Design Science Research (DSR) strategy (Lukka, 2003) for conducting the research project. DSR aims to produce innovative constructions, called artifacts, to solve real-world problems and to contribute to the theory of the discipline in which it is applied (Lukka, 2003). This project’s artifact consists of the adaptation of the WS technique, called LBWS, previously defined in the introduction section.

The research process of designing the artifact is being developed during the realization of three learning cycles, named Cycles 1, 2, and 3 (Figure). During each cycle, the four main phases that categorize this DSR were conducted. The four phases are: (1) understanding; (2) construction; (3) analysis; and (4) evaluation. The four DSR phases organize different approaches carried out by the research team in various rounds of visits in the same construction site. For that purpose, the authors used the Case Study (Yin, 2003) as the primary research method, as case studies offer flexibility for explorative and theory-building research in real-life contexts.

During the first learning cycle, the first version of LBWS was developed (Authors, year). The case study's findings led the authors to identify the utility of adding geographical location to the WS technique. The present paper focuses exclusively on presenting the results of the second learning cycle, comprising the second field test and its evaluation (see text in the rectangle highlighted in Figure 1).

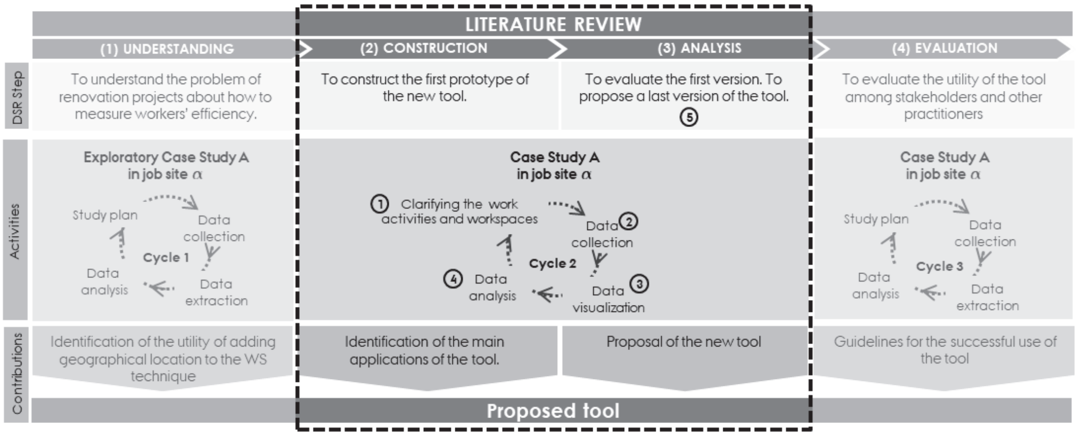

Figure 1: Research Design

CASE STUDY DESCRIPTION

The case study consists of a renovation project of 24 five-story housing buildings, a total of 597 housing units, originally constructed from 1950 to 1970 in Roskilde, Denmark. The case organization is one of the main contractors in the building sector in Denmark.

The contractor rented a façade scaffolding with plastic covering the entire temporary structure for each building under renovation. The scaffolding of some buildings is interconnected to facilitate workers' movement among the buildings. The scaffoldings included a cabin as the primary lift solution for material transport. Moreover, a mobile crane was used for lifting windows using hooks for installation and pallet lifts for transportation.

The main renovation tasks were conducted outside the buildings from the façade scaffolding and were mainly related to carpentry work, such as replacing windows and roofs, and painting work. Installing new ventilation and electricity systems represented the only two inside renovation activities. The contractor company placed modular containers within the job site for storage, administration, and changing rooms. The main material storage area, destined for inventory deliveries, is located next to the administration containers. Several work 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.

RESEARCH DESIGN

Cycle 2: Application of the LBWS and Evaluation

The second cycle presents five steps (see numbers in Figure 1). The first four steps consist of the application of LBWS (Figure 2), and the last step represents the evaluation: (1) clarifying the work activities and workspaces; (2) data collection; (3) data visualization; (4) data analysis; and (5) tool evaluation.

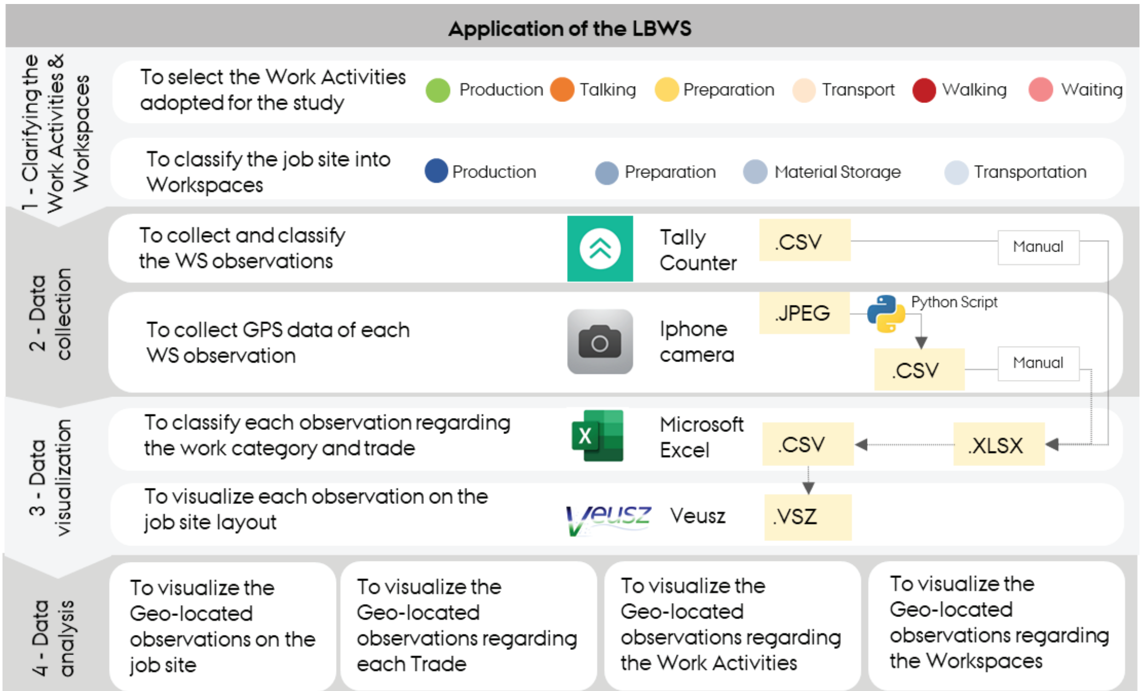

Figure 2: Application of the LBWS

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 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 on the roof; (2) talking, e.g., discussing the installation process; (3) preparation, e.g., measuring with a ruler the gypsum boards; (4) transportation, e.g., carrying tools and materials; (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 surrounding the production workspace; (3) material storage workspace, consisting of the container's area; and (4) transportation workspace, consisting of the area 1 and the material storage area.

Step 2: Data collection

Data was gathered in two rounds of visits, Round 1 and Round 2 (see Table 1). The data collection lasted seven days in Round 1 and five days in Round 2 (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 observers used a smartwatch to track the position during the random tours to guarantee that all the workspaces were observed. Although the time spent in each workspace was not the same during each tour, the results presented a relatively homogeneous sample.

The scope of the observations was limited to the trades that conducted their activities outdoors (N) during the period of visits. Those trades were: (1) Carpenter (N_1); (2) Mason (N_2); Electrician (N_3); (4) Ventilation (N_4); (5) Scaffolding (N_5); (6) Painter (N_6); and (7) Demolish (N_7). 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.

Table 1: Data collection characterization

Description	Period	Visits	Geo-located samples	Con. Interval	Sample (N)
Round 1	Weeks 45 & 46, 2021	7 visit days 8.5h/visit	n = 993 samples 142 average per day 39.8 std. deviation per day	95% ± 2%.	N =40 workers N_1=13 carpenters
Round 2	Week 20, 2022	4 visit days 8.5h/visit	n = 689 samples 172 average per day 41.2 std. deviation per day	95% ± 2%.	N ≈ 40workers N_1=13 carpenters

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. The purpose of the photo was to collect the geographic coordinates from each observation. Despite the fact that the coordinates represent the location of the observer instead of the task observed, this difference does not impact the results since the photos were taken as close as possible to the worker. At no time were individuals' faces or other identifiers registered; The authors extracted locations 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.). Thus, each geo-located observation contained the following associated information (Table 2): (1) photo; (2) timestamp; (3) trade observed; (4) work category; and (5) geographic coordinates, consequently, workspace category.

Table 2: Example of information associated with each geo-located observation

Photo	Time Stamp	Trade observed	Work category	Geographic coordinates	Workspace category
IMG-5548.JPG	2021.11.18; 13:33:05	Carpenter	Production	Lat 56.089999; Lon 12.309999; Alt 58.930754	Production workspace

Step 3: Data visualization

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. The authors collected the coordinates of the job site facilities and buildings using a smartwatch and converted them to a visual layout using the RouteConverter program. RouteConverter is a free Global Positioning System (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.

Step 4: Data analysis

The research team conducted the following four types of data analysis: (1) Visualization of the geo-located observations on the job site layout; (2) Distribution of the geo-located observations per trade; (3) Distribution of the geo-located observations per work activities; and (4) Distribution of the geo-located observations per workspaces.

Step 5: Evaluation of the LBWS

The utility of the LBWS was assessed according to its ability to accomplish its objectives. The objectives of this adaptation of the WS techniques are: (1) to facilitate the sharing of information of the WS technique; and (3) to support decision-making. The assessment is based exclusively on the empirical study presented in this paper. The set of six requirements that a VM should contain proposed by (Pedó et al., 2022) was used to assess the first version of the tool by the present authors.

Table 3: Set of six VM requirements (Pedó et al., 2022)

VM requirements	Definition
(R1) Simplicity	It is concerned with how easy it is to use a VM practice based on a clear understanding of its objective or function.
(R2) Standardization	It is related to whether there is repetition in using devices, i.e., regularity of information units, which can support accurate information delivery.
(R3) Availability	It is related to making updated information available at the right time and in the right amount, making it easy to prioritize information.
(R4) Accessibility	It considers how easy it is to access the information, i.e., if the information is located in the right place.
(R5) Flexibility	It is related to: (i) how easy it is to make changes, i.e., the possibility of adapting devices and practices according to the users' needs over time; (ii) how easy it is to update the information, i.e., changes can be quickly displayed in the device
(R6) Traceability	It is associated with easy storage of information and tracking its origin.

RESULTS

LBWS RESULTS

The LBWS results focus on the discussion of the use of the tool for the four sorts of data analysis previously presented.

Visualization of the geo-located observations on the job site

Figure 3Figure 3illustrates the distribution of the geo-located observations from one day of data collection from Round 1 and Round 2. There are 140 data points from Round 1 and 224 data points from Round 2. In Round 1, the carpenter trade constitutes a larger part of the observations than in Round 2.

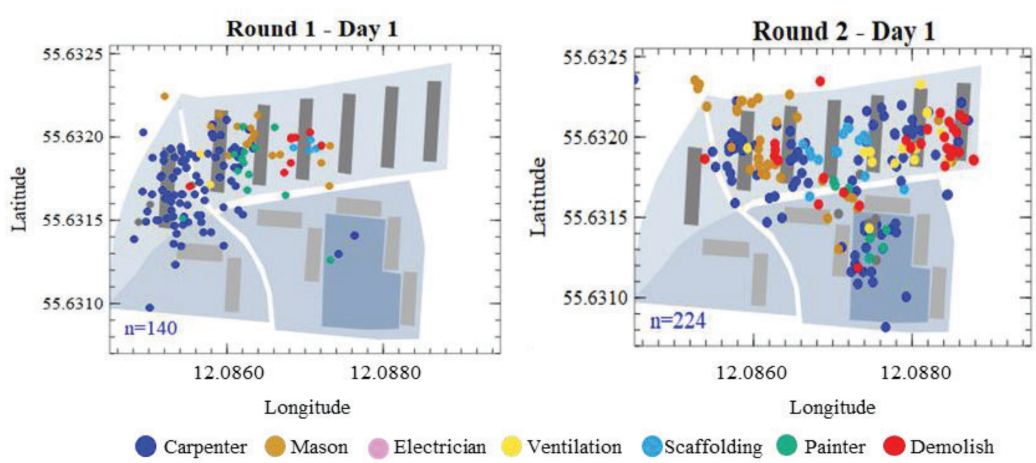

Figure 3: Geo-located observations of all trades during Day 1 of Rounds 1 and 2.

The visualization shows that there are not many similarities between the data from the two visits. During Round 1, most of the observations were concentrated on and around four of the apartment buildings, especially the building furthest to the left on the job site. Some observations were obtained in the transportation area south of the four buildings, and a few were recorded in the storage area. During Round 2, the observations were scattered across a larger part of the job site. The workers were seen on the scaffolding of almost all of the buildings as well as in the preparation workspaces between buildings, and a significantly higher number of observations were recorded in the material storage area compared to during Round 1.

Distribution of geo-located observations per trade

The geographic distribution of observations can be analyzed for each trade individually. In Figure 4, only the observations of the carpenter trade are included. As for the distribution of observations for all trades, the observations of carpenters are highly concentrated in one area during Round 1 as opposed to Round 2, where the observations are distributed across most of the job site. This means the carpenters were working in many different places during the visits of Round 2, both in the buildings and in the material storage area. The many workplaces also led to more observations in the transportation areas, as the carpenters needed to move between buildings more often.

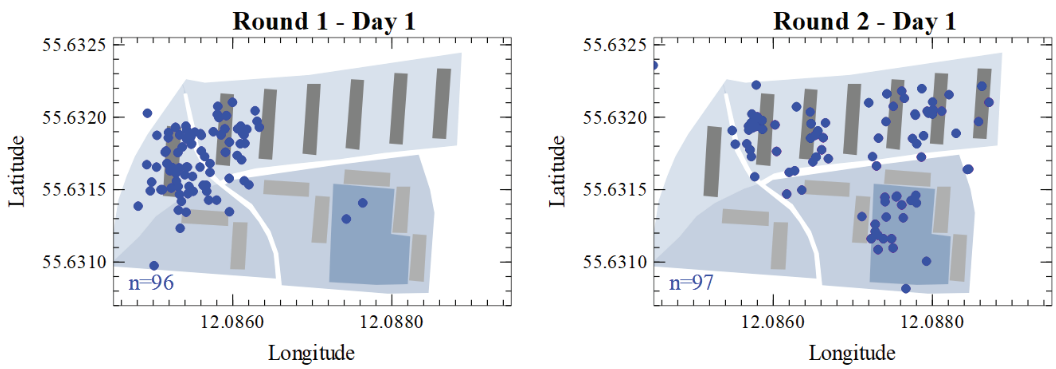

Figure 4: Geo-located observations of carpenters during Day 1 of Rounds 1 and 2.

Distribution of geo-located observations per work activities

In Figure 5, the observations of the carpenter trade have been categorized according to the work activity observed. The overall distribution of observations of the six work categories is shown in the pie charts.

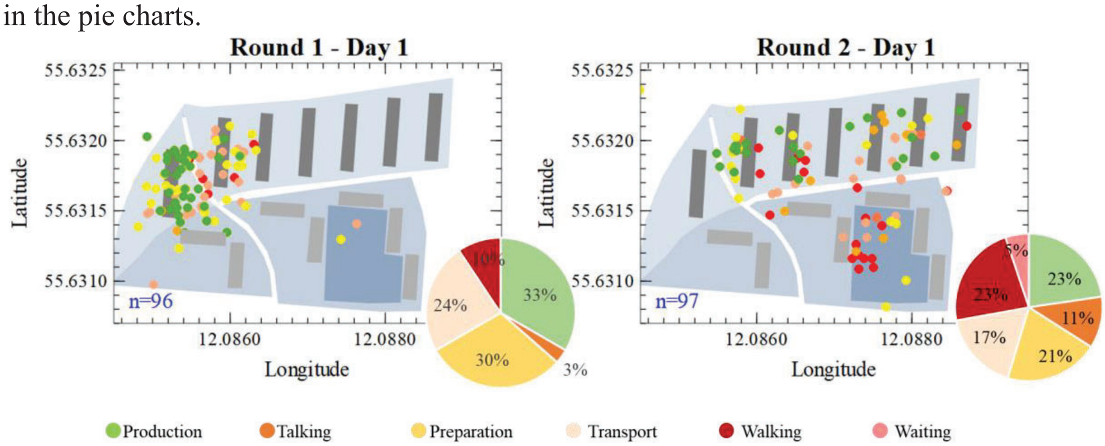

Figure 5: Positions of the carpenters' WS categories during Day 1 of Rounds 1 and 2

As seen in the figure and explained above, there were more observations in the transportation and preparation areas during Round 2 than during Round 1. The work being done in these areas is mostly non-value-adding activities such as walking and transportation, thus, the share of time spent on value-adding activities is significantly lower for Round 2 than for Round 1.

Distribution of geo-located observations per location

In Figure 6 (left), the positions of the carpenter trade observations for observation days 1 to 4 of Round 2 are illustrated. The coordinates of each observation are based on the geo-location of the photo taken of each work sampling observation. As the geo-location of each photo also includes a precise altitude value, the WS observation can also be distributed per level of each building, cf. Figure 6 (right). This visual information can serve multiple purposes, e.g., compliance checking of the location-based schedule and checking if carpenters were working on the location that was planned.

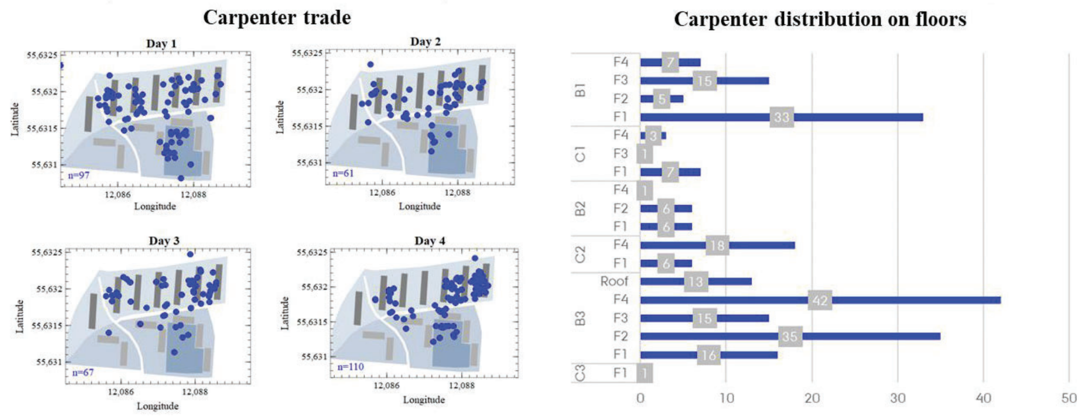

Figure 6: Longitude and latitude positions (left) and altitude (right) of WS observations for the carpenter trade per for round 2

In combination, these four types of visual data analysis of the location-based work sampling data can be used for many different purposes, such as documentation and analysis of plan and production system efficiency. This visual data can feed the production planning and control system and serve as VM to further improve the production system.

LBWS EVALUATION

The first requirement was simplicity, which is defined as how easy it is to use a VM practice based on a clear understanding of its objective and function. The objective of LBWS is to provide information obtained during the WS application based on adding geographic location information. The visual technique shows the observations made on construction trades and work categories in the foreground and job site spaces in the background. A number of different functions of LBWS have been demonstrated in this paper, and the visual representation of these functions is considered easy to comprehend.

The second requirement is standardization, which is related to whether there is repetition in using devices, i.e., regularity of information units, which can support accurate information delivery. This is very important for the operational level, as team members must be guided on how to use the practice correctly, allowing autonomy and valid data simultaneously. As the practice is still novel, standardization is ongoing. However, the data lakes are standard, i.e., geo-location, WS categories, site layout, etc. Thus, applied in repetition, the information provided to users holds a large degree of standardization.

Availability is the third requirement and focuses on making updated information available at the right time and in the right amount, making it easy to prioritize information. For all the four functions described in LBWS, it is easy to update the data file and produce new visual outputs. Both Work Sampling data and Location data are based on .csv files, cf. Figure 2. However, the update process currently includes some manual steps. Filtering the information is easy in the Veusz program.

Accessibility is the fourth requirement and is defined as how easy it is to access the information, i.e., if the information is located in the right place. The main users of the LBWS practice are likely also those who orchestrate the data collection and carry out the data analytics. Thus, the main users have very good accessibility to the information provided by LBWS.

The fifth requirement is flexibility, which is related to how easy it is to make changes and adapt to the user's needs. As described, the four functions of LBWS are the practice's main utility. Other functions and analyses might surface, and it should be easy to amend to such user requests, as the process of data acquisition and data analytics is simple and standardized, cf. Figure 2. However, some of the steps of converting data require insight and knowledge of the data collection and are also quite time-consuming.

Traceability is the sixth and final requirement. It is associated with easy storage of information and easy tracking of the origin of the information. The system has full transparency, i.e., every graphic representation is directly linked to one or more data sets that correspond with time, place, trade, etc. The practice does, however, not have a versioning system, meaning old versions cannot be accessed if the users have not saved these deliberately. In Table 4, a summary of the evaluation of the six requirements' fit with LBWS is presented, based on a high/medium/low assessment.

Table 4: Assessment of the six VM requirements on LBWS

VM requirements	High/Medium/Low evaluation of LBWS
Simplicity	Evaluated as high. A clear objective of LBWS is present. Several different functions with a clear visual representation.
Standardization	Evaluated as medium. Data lakes are standardized, and processes for harvesting data lakes are described.
Availability	Evaluated as medium to high. Some of the data processing is manual, however easy and standardized.
Accessibility	Evaluated as high. Information is likely generated by the main user who also organizes the data collection and analytics.
Flexibility	Evaluated as medium. The practice is adaptable to new user requests, however some of the processes of data conversion requires insight and time.
Traceability	Evaluated as high. There is a clear link from the graphical output down to the data source. This is very transparent.

DISCUSSION

The main contribution of this study is the adaptation of the widespread WS technique, named LBWS. This new adaptation can be seen as a VM practice combined with digital technologies. As pointed out by (Tezel & Aziz, 2017), the combination of VM and ICT contributes to an increase in the degree of automation in project control, increasing efficiency in data collection and processing, and reducing the feedback time.

LBWS has also been assessed in relation to requirements of VM with focus on digital VM practices (Pedó et al., 2022). Overall, it is assessed that most of the requirements, to a high degree, are fulfilled in LBWS. As the development of LBWS as a VM practice is still ongoing, the next paragraph will discuss future steps, particularly how LBWS can be implemented and integrated into daily managerial routines and processes.

Implementing VM in construction projects poses additional challenges in comparison to manufacturing due to the complex and project-based nature of construction (Valente et al., 2019). In construction, VM should increase the involvement of workers in continuous improvement efforts (Bernstein, 2012) because it allows for rapid understanding of and response to problems (Bateman et al., 2016). Valente et al. (2019) advise a 4-step model for devising digital VM practices for production management in construction. The first step is an observation phase, where the problem itself is investigated. This step has already been documented for LBWS, cf., the DSR cycle. The second step is to identify the user and user needs to identify the level of visual literacy, which information is required, types of data, etc. The user needs have partially been described in the results of LBWS, showcasing four different functions the practice can offer. However, a future step would be to conduct focus group workshops with industrial experts to elaborate further on user needs. This focus group workshop would also be useful for the fourth and final step, namely defining the final visual attributes. These four steps to implement a digital VM practice complies with the VM typology presented by Brandalise et al. (2022). The final level in their typology is the integration into daily managerial routines. This needs to be further formalized for LBWS, as it currently offers a number of functions, i.e., visual information analysis types, that can be used to identify problems and potentials of the production system.

CONCLUSION

The LBWS is, to the authors' knowledge, one of the first adaptations of the WS technique with ICT application. It brings together the workers' distribution of time into work activities, as the traditional technique, and the geographical location of the WS observations. It presents visual information, i.e., WS data on a map or site layout drawing. Four different types of information and analysis useful for project and site management have been showcased. For this presentation purpose, data from a case study was applied. Although different data like WS categories and location data were collected, the duration of the field tests and the depth of integration in company information systems are insufficient to provide conclusive results of the utility of LBWS.

The utility was assessed by evaluating LBWS with respect to six requirements of digital VM. Overall, the assessment was positive, however, it was recognized that additional implementation steps are needed, in particular with respect to further analyzing user needs and how to integrate into process routines. Several recommendations were made for improving the tool, among them to conduct focus group workshops with industrial experts. While the results are positive and indicate the value of LBWS-enabled process control, further development and testing are needed.

Another significant limitation of the tools is the manual data collection process, which can be laborious and error-prone. Moreover, the accuracy of the locations of the workers collected from the photos could have impacted the results. Other tools for gathering workers' coordinates (e.g., GPS trackers) should be tested in future studies. Lastly, the tool provides delayed information, not contributing to conducting real-time analysis.

ACKNOWLEDGMENTS

This work was supported by Research Fund Denmark (grant no. 0217-00020B). The authors are also grateful for the Case contractor that opened its door for this study.

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