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Implementing Digital Visual Management: Case Studies on Barriers and Enablers

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Abstract

Question: The architecture, engineering and construction industry (AEC) has an increasing interest in achieving better situational awareness (SA) in complex projects. The implementation of digital visual management (DVM) tools as a means of communication to increase SA in AEC projects has the potential to simplify information dissemination. What are the barriers faced during the implementation of DVM? Is it possible to identify factors that can facilitate implementation?

Purpose: The purpose of this paper is to identify the barriers encountered during the implementation of DVM and to identify possible countermeasures to overcome such barriers.

Research Method: 21 interviews were conducted with project management professionals who implemented DVM in four projects in Finland.

Findings: Barriers include technological limitations on data collection and sharing of information, cultural mistrust among project participants, and increased work for data collection. On the other hand, the findings show that lean principles, such as the openness of the environment to share information, the standardization of work, and continuous improvement, have the potential to facilitate DVM implementation.

Limitations: Interviews as a research method are limited due to their subjective nature. In

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addition, the interviews were limited to Finnish projects and complex infrastructure project management professionals. Thus, the results and explanations do not necessarily generalize to other construction industries or project types.

Implications: Project teams that desire to implement DVM or that are implementing DVM can now identify expected barriers and plan possible ways of overcoming them during implementation in advance. The identified enablers contribute to knowledge about DVM and can offer practical guidance during the implementation of these strategies.

Value for authors: This paper identifies barriers and enablers to the adoption and implementation of DVM.

Keywords: visual management, digital visual management, situational awareness, construction

Paper type: Full paper

Introduction

The complexity of construction projects requires information sharing to increase and spread situational awareness (SA) among project participants. SA is defined as the perception of environmental elements in time and space, comprehension of their meanings, and projection of future outcomes (Endsley 1995). Shared SA in complex projects in the architecture, engineering and construction industry (AEC) results in a better understanding of the task flow and easier identification of problems, combined with a more efficient decision-making process (Lappalainen et al. 2021).

To increase SA, visual communication and visual management (VM) have been successfully implemented and documented in distinct phases of construction projects (Tezel 2011; Pedó et al. 2022). The use of performance dashboards to visually display and share key performance indicators (KPIs) has been continuously applied during complex projects, creating an important link between project-controlling activities and the use of VM in the distribution of shared SA (Shermach 2005).

Other promising tools capable of increasing SA in construction projects are related to digitalization and information technology (Olivieri et al. 2017, Dror et al. 2019, Pica and Abanda 2019). These tools allow system-to-system, human-to-system, and system-to-human communication, enabling more effective data collection and sharing with the right person at the right time (Dave et al. 2015). The combination of digital tools and VM has opened the field to digital visual management (DVM) concepts and tools (Tezel et al. 2017).

DVM has the potential to both provide information visually and allow for more effective information sharing (Tezel et al. 2017, Pedó et al. 2022). However, so far, in the CI context, the benefits of DVM have mostly been discussed (Pedó et al. 2022). Barriers to DVM implementation have been proposed in conceptual studies (Tezel et al. 2017). Because these systems are not yet widely used, there is a need for more knowledge about the barriers and enablers related to implementing them.

This paper aims to: 1) identify common barriers and 2) identify enablers to the adoption of DVM tools, and 3) understand the current stage of DVM adoption in the AEC. The adoption

of DVM was explored in four complex infrastructure case studies in Helsinki and Espoo, Finland. To identify the barriers to and enablers of DVM implementation, the researchers interviewed 21 project management professionals.

Literature Review

Process and flow visibility continue to be major problems for AEC projects. In recent years, the academic community and practitioners have increased their interest in the studies and applications of SA models and systems in the AEC (Lappalainen et al. 2021). Such interest stems from the fact that the information bottlenecks, as well as the costs and time involved in collecting, updating, and sharing data, are also symptoms of the lack of SA in construction projects (Akinci 2014). The adoption of VM strategies has the potential to improve information sharing and visualization in AEC (Inshu et al. 2023), thus increasing shared SA in projects.

VM as a strategy to increase process transparency has been investigated both in manufacturing and in AEC (Galsworth 1997, Liker 1997, Tezel et al. 2015, Kurpjuweit et al. 2018). The literature presents different definitions of VM. It has been described as a sensory communication strategy for increased transparency of processes (Tezel et al., 2015) and an information-sharing practice that enables continuous improvement (Imai 1997). We use the definition of the Toyota Production System (TPS), where VM is connected to Lean Management and focuses on the visual representation of information that can be retrieved at a glance during the execution of tasks (Koskela 1992, Galsworth 1997, Liker 1997, Formoso et al. 2002). In this context, VM devices can be applied to signal, limit, and guarantee the correct execution of a task at the correct moment (Shingo 1989). They can also increase the transparency of flow and make the execution of tasks self-explaining, self-ordering, and self-regulating. This facilitates continuous improvement (Galsworth 1997).

The manufacturing industry has reported good results in adopting VM strategies (Sugimori et al. 1977, Shingo 1989, Galsworth 1997). This has inspired AEC researchers and practitioners to implement VM in construction projects (Koskela 1992, Formoso 2002, Tezel 2009, Koskela et al. 2018). VM strategies implementing Kanban, Poka-yoke, and Andon systems have been studied. Studies have reported successful outcomes when tackling common AEC problems, such as a lack of flow visibility and understanding and low process transparency (e.g., Tezel et al. 2010, Biotto et al. 2014, Bascoul et al. 2017, Brandalise et al. 2018).

Research on how information and communication technologies (ICTs) can be utilized in VM strategies has followed the increasing digitalization in the AEC (Sacks et al. 2010, Tezel et al. 2017), and the implementation of DVM prototypes has highlighted the potential of increased information sharing and process transparency (Sacks et al. 2010, Dave et al. 2014).

The potential of implementing VM and DVM to increase SA in AEC projects has been researched but without establishing a clear connection between the terms and principles (Tezel et al. 2017, Pedó et al. 2022, Lappalainen et al. 2021). The current literature on DVM finds that VM and DVM systems have the potential to facilitate information flow (Tezel et al. 2017, Valente et al. 2018, Pedó et al. 2022) without a direct correlation with SA. Research on

the implementation of SA systems has focused on design stability (Lappalainen et al. 2021) and the managerial perspectives of the adoption of SA systems (Lappalainen et al. 2024).

A set of VM requirements applicable to digital support and control during the design phase has also been examined (Pedó et al. 2022), and the development of a DVM tool for construction workers was recently evaluated (Kiviniemi et al. 2024).

The investigation into the challenges and barriers to VM and DVM adoption in AEC projects continues to be limited. Tezel et al. (2017) highlight in a conceptual paper the following barriers to the adoption of information technology-based VM: (1) interoperability issues among emerging technologies, (2) initial technology investment and maintenance costs, (3) lack of human capital that is competent in both Lean Construction processes and emerging IT, (4) lack of best practices and exemplary cases, (5) lack of proof of return on investment, and (6) the project-based, fragmented and highly competitive nature of the industry. Reinbold et al. (2022) identified the following challenges during the investigation of three case studies in Finland: (1) no use of VM or DVM focusing on the production phase of the AEC project, (2) lack of involvement and support from stakeholders, (3) neglecting information needs from the production area, (4) misunderstanding between the availability of visual information and visual pollution, and (5) that the DVM devices followed analog logic, where the data were collected and treated manually.

While existing studies have examined the challenges and barriers to implementing DVM, there is a notable absence of research focusing on the potential enablers that could ease this process. Understanding both the barriers and the enablers is crucial and could significantly enhance the adoption and effectiveness of these approaches in practice. This study aims to identify the barriers encountered during DVM implementation and to investigate the various factors that could facilitate the successful implementation of DVM, thereby addressing this critical gap in the research.

Methods

The study was conducted in two phases. Phase 1 focused on the literature review regarding the adoption of DVM in the construction industry and the already identified barriers and facilitating factors to the implementation. In Phase 2, a multiple-case study was the necessary strategy to understand the current stage of DVM implementation and to identify barriers and enablers encountered during DVM implementation in AEC projects. Figure 1 illustrates the two phases of the research strategy.

The multiple case study design was chosen as a research method because it allows the observation in practice of the current adoption of DVM in complex AEC projects while providing several sources of data collection through interviews and usually representing more robust results than single case studies (Eisenhardt and Graebner 2007).

The proposed research method was four case studies of Finnish infrastructure projects. The cases were selected because they adopted and implemented DVM strategies in complex infrastructure projects in the AEC. Disruption and recovery are often research opportunities

worth documenting and analyzing, since the findings often reveal insights into general processes (Yin 2018). Table 1 describes the cases studied.

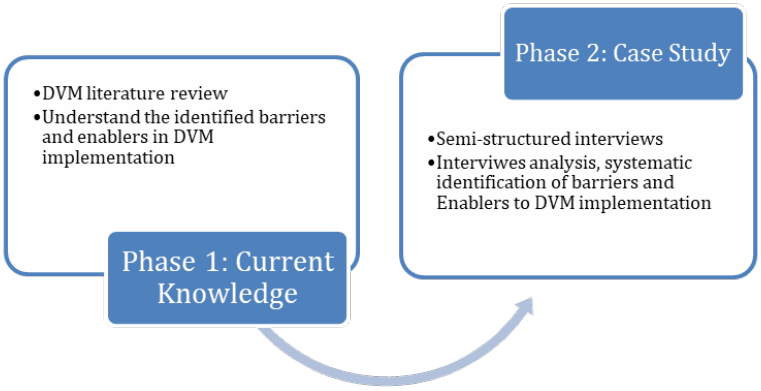

Figure 1. Research phases

The location of cases in Finland allowed the researchers access to the research data and enabled them to conduct face-to-face semi-structured interviews with DVM users. All interviews were conducted in Finnish by two researchers, one interviewing and the other observing and taking notes. Three of the interviews were conducted online. Interviewees were asked to describe the DVM they used, including its functions, applicability, and the information it provided. They were also asked to describe the connections between the DVM and different aspects of the project, such as design, procurement, and logistics, and to identify any functionality that was automated. Interviewees were also asked to describe recent cases in which they or someone else had used DVM in a user role. Table 2 provides background information about the interviewees.

Table 1. Case studies description

CASE STUDIES			
Case Study	Project Type	Project Phase	Project Budget (M€)
A	Subway line	Commissioning	1200
B	Light rail line	Construction	350
C	Tram rail line	Construction	200
D	Railway Line	Design	70

The duration of the responses reflects the fact that the research project also included questions and themes other than DVM. The duration of the interviews included all themes, not just the time spent by the respondent on the DVM theme.

The approach used in this study aimed to gain an in-depth understanding of the use of DVM in project management (Fellows and Liu 2021). To investigate the convergence of the findings (Yin 2018), the authors transcribed the interviews, and the quotes were open-coded according to themes and categorized using Atlas.ti software. The inductive coding employed adhered to a structured methodology: (1) analysis of the text to discern intrinsic meanings, (2) identification of pertinent text segments, (3) categorization of these segments—either by

assigning them to pre-existing categories or by establishing new ones—and (4) elucidation of the interconnections among categories to construct a cohesive analytical framework (Fereday and Muir-Cochrane 2006). This was succeeded by a phase emphasizing categorization and relationship cultivation. We adhere to the methodology of Williams and Moser (2019), who contend that open coding entails the segmentation and analysis of raw data; nonetheless, the processes of categorization and connection building necessitate continuous review, cross-tabulation, and refinement, which were conducted throughout the progression of the work.

We employed typing to organize the detected concepts, an approach that categorizes an extensive array of codes according to shared attributes and maintains conceptual significance despite minor discrepancies (Vaismoradi et al. 2016). We organized the codes into logical categories that encapsulated their attributes and dimensions (Friese et al. 2018). To enhance analytical depth, we employed the continuous comparison method (Glaser and Strauss 1967), which enables iterative data comparison to improve developing themes. We employed axial coding (Corbin and Strauss 2015) to investigate causal links among categories, hence enhancing the interpretive framework of our findings. Ultimately, we classified participants' replies based on principal themes. Then, the authors cross-referenced the coded quotes with the case studies, allowing them to examine the convergence and non-convergence of themes.

Table 2. Informant description

INFORMANT DESCRIPTION			
No.	**Role**	**Employer**	**Interview duration (minutes)**
1	Project director	Consulting company	107
2	Construction director	Owner	107
3	Site manager	Owner	76
4	Project engineer	Consulting company	77
5	Project engineer	Consulting company	82
6	Project engineer	Consulting company	74
7	Scheduling manager	Consulting company	78
8	Financial director	Owner	62
9	Project manager	Consulting company	50
10	Project engineer	Consulting company	69 (Online interview)
11	Design manager	Consulting company	63
12	Project manager	Construction company	61
13	Risk Manager	Consulting company	51
14	Cost Manager	Construction company	52
15	Production Manager	Construction company	82
16	Financial Manager	Construction company	50 (Online interview)
17	Design Manager	Consulting company	58
18	Project Manager	Construction company	66

19	Development engineer	Software and service provider	76
20	Owner's representative*	Public roads agency	76 (Online interview)
21	Project manager*	Consulting company	76 (Online interview)

*) The interview was conducted at the same time

Table 3 presents the questions that guided the interviews. As the interviews were semi-structured, other themes, like contractual aspects, were also introduced by the interviewees.

Table 3. Semi-structured interviews questions

Probe questions	how the DVM works, how it is used, what information it presents, how you use it, how the group uses it. To which areas of the project / production / processes is the system connected? Eg. design? Procurement? Logistics? And are parts of it automated? How would you define your role as a SA and DVM user (Input, Output, Observer, etc.)? Do you enter/add any information into the system yourself? If you enter, what information do you enter yourself? And what information in the system do you utilize the most of yourself?
Quality of DVM and SA data	- From what sources is SA and DVM information collected? - How is DVM information collected? - Are there / What differences have you noticed in the DVM data collected from different sources? - How confident are you about the DVM? - How accurate and reliable is the DVM information? - When was the last time you suspected any information in the SA system/DVM report? Why did you doubt it? - How do you deal with situations where DVM information is not reliable? - How often is the information updated in the DVM? - Is all data updated at the same time or does it vary by data type / source? - How does outdated information appear in the SA screens / boards (DVM)? - How old do you think SA information can be that it is still useful in your work? - Describe the situation (s) where the SA information you need is missing. What happened, why and how did the situation was corrected? - What unnecessary / inaccurate information you would remove from the DVM if you could decide. - When was the last time you saw some decision “left open” / undecided due to the poor quality of the DVM report / suspicious source / conflicting information / outdated information? How are such situations usually handled? - What are the general inconsistencies in the SA data based and DVM report on your experience? Where can they come from?
Visual presentation	- What kind of interface is it, how do you use it? - Describe how the SA information is presented visually in your system (in this context it is also possible to look at the DVM board / screen, which allows the interviewee to present it to the interviewer) - What kind of symbols are used in it? ask the interviewee to describe what the symbols mean to the user (and observe / photograph) - What in the view/screen attracts the viewer's / user's attention, what information is centrally displayed, what information is on the side / hidden? - How are key metrics displayed? how do goals appear? - Explicit (precise, clear, detailed information): what kind of key figures are on

	the screen/board, what they tell (the interviewee answers in his / her own words, the research-er observes / photographs and records his / her observations on a separate form). Are any limit values / alarm limits visible? If so, what are they? - Implicitity (indirect, interpretable information, tacit knowledge): what should be deduced from the SA (presented by the interviewee)? What do the key metrics tell you how much in-formation on the screen you need to be able to interpret? Do you / the group often have any information that does not appear on the screen/board but is relevant to the SA? How is this indirect / tacit information handled? - What would you change in the visual presentation of the DVM if you could decide? what would you add / remove from the view? what would you change in the interface?

DVM Systems and Report

The interviewees employed four distinct DVM systems in their projects. Table 4 describes the attributes of these systems.

The reports generated by the systems were similar and focused on the same KPIs. Due to the paper's length limitation, just DVM system A is described in detail.

Table 4. DVM system descriptions

DVM system A: A physical space with touchscreens displaying project KPIs updated every one to two weeks by on-site project management contractors and a five-person status team. Data were collected using spreadsheets and web-based tools without automation or sensors. The project team developed the system, ensured data quality and availability, and analyzed data for biweekly project management meetings. Project scheduling, cost forecasting, and safety were system priorities. During project commissioning, final documentation and testing were monitored. See Figure 2.
DVM system B: In-house system to aggregate reports and collect data from various digital systems. The system overseer manually compiled data into PowerPoint monthly for the project's data management system. The subarea managers were responsible for data accuracy. Monthly SA sessions with a one-to-four-week data collection schedule let project managers evaluate progress and forecasts. Cost and schedule forecasts, health and safety, and clear KPI explanations were covered.
DVM system C: The dashboard integrates project-level data from multiple sources. A smartphone app logs anomalies and problems, while software interfaces provide other data. Little manual input is needed because partner software provides the most data. System development began in a spreadsheet and was incrementally integrated. The main dashboard uses a public business intelligence cloud service. Instead of sensors, the dashboard displays current drone photos. The system digitally captures design status data.
DVM system D: The office software-based system tracks project KPIs, including schedules, costs, and health and safety. Data are stored every one to four weeks in a commercial business intelligence cloud service. Only certain KPI data were functional during the investigation because the system was still developing. Sensor data were excluded. System data assessments occur weekly in construction management team meetings, which focus on schedules and budgets.

The goal of DVM system A was to standardize the reporting of construction site KPIs to improve the shared SA of stakeholders. The chosen type of report was a dashboard that followed seven lagging KPIs: 1) the percentage of work planned, 2) the percentage of the work completed, 3) the deviation between planned and executed work in percentage, 4) planned costs in million euros (M€), 5) executed costs (M€), and 6) health and safety in percentage, and 7) collaboration work in percentage. Concerns were raised about ensuring the report's comprehensibility and accessibility to all stakeholders. Consequently, visualization and color coding were implemented.

The report adopted is represented in Figure 2. If there were no delays, the schedule report had a green circle. If the work were delayed, the circle would be red. A Finnish method was used to measure occupational health and safety. The measure is based on the share of successful health and safety observations of the total observations. For this health and safety KPI, the green color was used for indicator values above 95%; otherwise, the KPI was red. Collaboration was measured via a questionnaire responded to by those involved in the project, and the KPI measured the share of positive answers. For the collaboration KPI, the circle would be represented in green for indicator values above 80%; otherwise, the circle would be represented in red. Other KPIs related to the quantity of work executed and quantities were also followed.

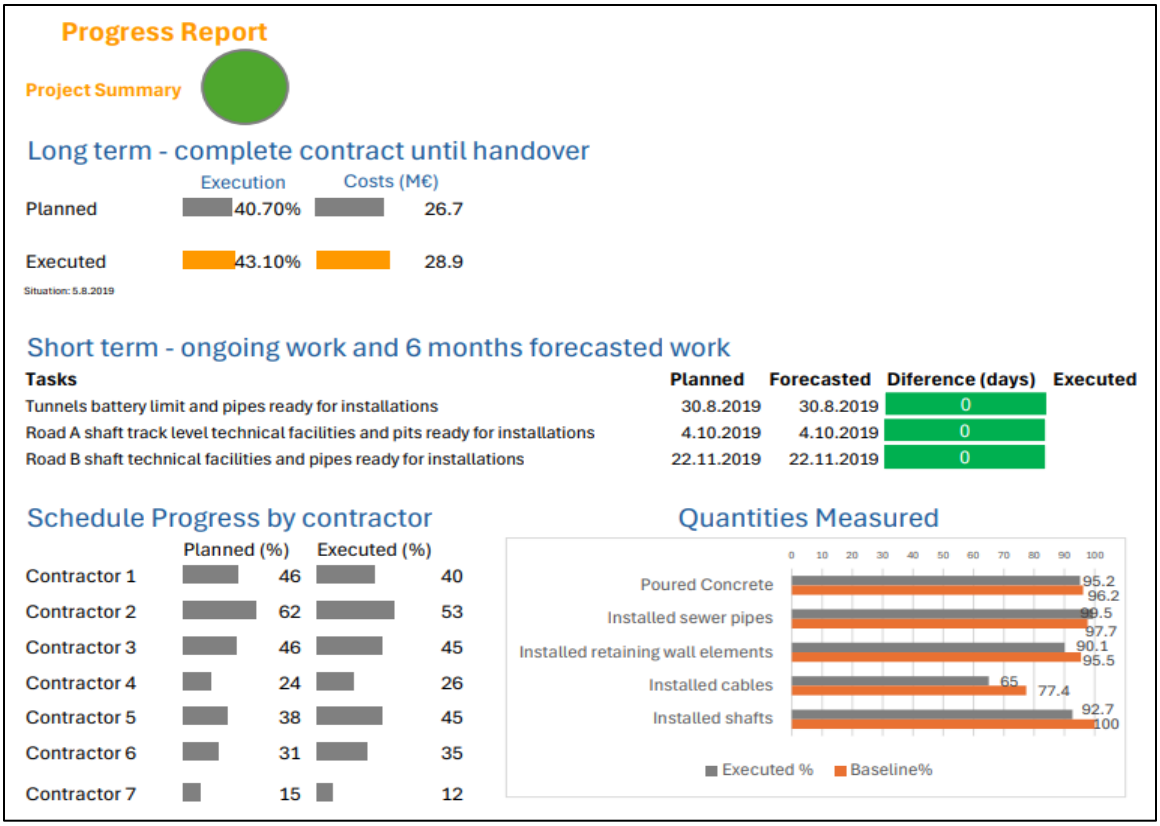

Figure 2. Visual Report of KPIs adopted during project A (Source: adapted and translated from Finnish to English by the authors)

To increase the shared SA, the reports were displayed digitally in a "War Room," a management room for the project that was accessible to the stakeholders. A picture of the digital display of the reports is shown in Figure 3.

Figure 3. Digital displays of Project A Reports (Original photo: Timo Kauppila, NDAV)

Barriers and Enablers to DVM Implementation

For analysis, the authors selected quotations that mentioned digital reporting, visual features of the report, and automation of data collection. These themes were selected using an inductive approach due to their correlation with DVM implementation. From this first screening, 126 quotations were included in the analysis.

The authors created two subcategories: one related to the barriers faced during DVM implementation and another that encompasses possible enablers of the implementation. In each of the previous two groups, the data were categorized according to 1) information and communication technology (ICT) and tools, 2) process, and 3) people and culture.

These data were tabulated and cross-referenced by the case study in which they were identified. There were barriers identified in all the projects, such as the lack of standards for information sharing, lack of interoperability among systems, increased work for manual data collection, publication of outdated data, lack of trust among project members, and a shared culture of hiding information, corresponding to a convergence of findings. It was also possible to identify barriers that were only identified in one of the cases, such as the lack of understanding of the DVM report utility in Case Study A, evidencing that non-convergent findings were also identified.

Table 5 lists the barriers encountered during DVM implementation, noting the case study in which they were noticed.

Table 5. Barriers to DVM implementation identified in each project

			Project			
			A	B	C	D
Barriers	ICT & tools	Lack of standards for information sharing	x	x	x	x
		Use of different systems for different data	x	x		x
		lack of interoperability among systems	x	x	x	x
	Data Collection & Publishing	Increased work for manual data collection and analysis	x	x	x	x
		publication of outdated data	x	x	x	x
		lack of understanding of the report and utility	x			
	People & Culture	Lack of trust among project members	x	x	x	x
		Mistrust of data collection methods	x	x	x	
		Lack of commitment from the project actors towards the reporting	x	x		
		A shared culture of hiding information	x	x	x	x

Similarly, it was possible to identify common factors that facilitated the implementation of DVM in all case studies. The increase of shared SA with DVM implementation, the DVM as a facilitator to the information sharing, the involvement of project stakeholders during the DVM implementation, and the need for continuous improvement when implementing DVM are enablers shared among the case studies, once again showing convergence of findings. For Case Studies B and C, the standardization of reporting with DVM was identified as a facilitator, and for Case Studies A and B, having an open environment that fosters and encourages information sharing was an identified facilitator to the DVM implementation, resulting in a partial convergence of findings. Table 6 lists the enablers encountered during DVM implementation, noting the case study in which they were identified.

Some of the quotations were assigned to more than one subcategory. For example, the quotations that mentioned data collection and lack of trust in the reported data were categorized as *both* ICT and tools *and* people and culture because they pointed to the lack of digitalization in the data collection and analysis and emphasized that the data reported and collected were not always trustworthy. The following sections describe the findings of Tables 4 and 5.

ICT & Tools Barriers

All quotations that mentioned tools for data collection and analysis, adoption of new tools and systems, information systems, information silos, and interoperability issues were were classified under the ICT and tools subcategory.

Table 6. Enablers of DVM implementation identified in each project

			Project			
			A	B	C	D
Enablers	ICT & tools	Ensure that implemented DVM increased project understanding and shared SA	x	x	x	x
		Ensure that standardization of reporting with DVM facilitates communication		x		x
	Data Collection & Publishing	DVM facilitated information sharing	x	x	x	x
		Standards for information sharing increased the information reliability	x	x		x
	People & Culture	Commitment of project stakeholders to DVM implementation	x	x	x	x
		Open environment that fosters and encourages information sharing		x		
		Continuous improvement allowing DVM adaptability and flexibility	x	x	x	x

Several interviewees expressed concern that the lack of a standard and unified tool for reporting increased the workload. The adoption of a standardized DVM report required training of the project members involved in the reporting phase, their work tools, and processes adaptation and adjustments in the reporting process. These points created resistance to the adoption of DVM reporting. The change process was not considered a smooth transition but rather a contractual obligation.

Two other significant barriers to the adoption of the DVM report were manual data collection and analysis; these two barriers were noticeable across the four case studies. Another barrier identified in all the analyzed case studies was that different systems were used to follow up on the various aspects of the construction progress. An interviewee from Case Study A mentioned the use of five different ICT systems: financial reports, schedule monitoring, health and safety data and reporting, and tracking the quantities completed on the construction site. It turned out that to consolidate all the information into the DVM dashboard (Figure 2), the data was extracted manually from these different systems, which required time and was considered inaccurate by the interviewees.

It was clear that in all case studies, the systems used were not interoperable, and the extraction and exchange of information had to be processed manually, which is an important challenge to be addressed when digitalizing reporting and implementing DVM approaches in construction projects.

The barriers related to ICT and tools are summarized below:

- Lack of Standardized Tool: Several interviewees highlighted that the absence of a standardized tool for reporting increased workload.
- Training and Resistance: Adopting the standardized DVM report required training for project members, adaptation of work tools, and adjustments in reporting processes, which led to resistance.

- Manual Data Collection and Analysis: Manual data collection and analysis were identified as significant barriers to DVM report adoption, prevalent across all four case studies.
- Use of Multiple Systems: Different systems were used to track various construction aspects (e.g., financial reports, schedule monitoring, health and safety data), leading to data being manually extracted for DVM dashboards.
- Data Consolidation Challenges: Data extraction from multiple systems was time-consuming and considered inaccurate by interviewees, highlighting inefficiencies.
- Interoperability Issues: In all case studies, the systems were not interoperable, which poses a major challenge for digitalizing reporting and implementing DVM approaches in construction.

Data Collection and Publishing Barriers

This subcategory includes mentions of necessary changes in both the data collection and reporting processes that were identified in the interviews conducted in Case Studies A and B. For the interviews in Case Studies C and D, there were no quotes regarding the data collection and publishing, evidencing a partial convergence of findings among the case studies. Reporting process issues, such as the contractors' neglect and delay in publishing information and the increased workload in processing the reports, are covered as well.

For Case Study A, the processes for creating DVM reports were developed only due to the contractual obligations to produce and update such reports, which generated negative feedback related to project reporting. Many of the interviewees stated that the DVM reports contained unnecessary information, the updating of the information was often inaccurate, the same status was repeated over the weeks, and reporting was not prioritized.

This resistance to the implementation of DVM reporting was also often perceived as an underrating of the utility and importance of the report in Case Study A. Some of the interviewees involved in DVM reporting perceived it as an extra task to repeat the same information that had been reported previously, but in a different way. This can be identified in Case Studies A and B and reflects the lack of standards in the AEC, as well as how management and tools differ from one project to another.

As project organizations change from one project to another, the implementation of DVM tools and reporting is not a standard process, which poses a barrier to the consolidation of the adoption of such approaches.

The data collection and publishing barriers are summarized below:

- Reporting Process Issues: Issues such as contractors' neglect and delays in publishing information, as well as an increased workload in processing reports, were discussed.
- Contractual obligations: The creation of DVM reports in Case Study A was driven by contractual obligations, leading to negative feedback about the reporting process.
- DVM Report Criticism: Interviewees in Case Study A felt the DVM reports contained unnecessary information, were often inaccurate, repeated the same status over weeks, and were not prioritized.

- Resistance to DVM Reporting: Resistance in Case Study A was linked to undervaluing the report's utility. Some interviewees viewed the DVM report as an extra task, essentially repeating the same information in a different format.
- Lack of Standardized Process: As project organizations change between projects, the implementation of DVM tools and reporting is not standardized, posing a barrier to broader adoption.

People & Cultural Barriers

All mentions of resistance to the implementation of a new process, mistrust in the reporting partners, the belief that someone was hiding information, the lack of information sharing with others, and the change of behaviors toward the DVM after its implementation were classified under the *culture of mistrust and resistance* subcategory.

In the interviews, the mention of resistance to the implementation of the DVM reports was identified for different reasons. Resistance to the adoption of a new process and a novel manner of reporting, which belongs to the *people and culture* subcategory, is present in all case studies. The changes should be dealt with before the implementation phase, and the discussions must clearly state the importance of DVM and its benefits to the project. The contractual obligation is not enough to ensure the success of the implementation. It can even contribute to resistance.

The most common mention regarding people and culture is related to a lack of trust. The existing culture of mistrust in the AEC was identified in these cases. In all case studies, interviewees brought up the issue that contractors concealed information or tried to do so by manipulating shared data and information. This mistrust encompassed how data were collected and by whom. For Case Studies A, B, and C, interviewees stated that when the data were collected and analyzed manually, the reports often contained outdated information, or the published information did not reflect reality. Mistrust was at least partially based on real, untrustworthy behavior. Some of the interviewees in Case Study A admitted that they also had hidden information in some situations.

The mistrust culture is a major barrier to be overcome during DVM implementation, as it undermines trust in both the information and the shared SA. It also raises doubts about the decision-making process, since the parties involved might make decisions based on outdated and mistrusted information.

The people and culture barriers are summarized below:

- Resistance to DVM Adoption: Resistance was noted across all case studies, due to the novelty of the reporting process and the new approach.
- Change Management: Changes should be addressed before implementation. Clear discussions on the importance and benefits of DVM are necessary, as contractual obligations alone are insufficient for successful adoption and may increase resistance.
- Lack of Trust: The primary cultural issue identified was a lack of trust. Project members believe that there is concealing or manipulating data in all case studies.

- Data Collection Issues: manual data collection led to outdated or inaccurate information in reports, further fueling mistrust in the process.
- Impact of Mistrust on DVM Implementation: The mistrust culture is a major barrier to DVM implementation as it undermines confidence in shared information and decision-making, leading to decisions based on unreliable or outdated data.

ICT and Tool Enablers

Under the ICT and tools subcategory, the interviews mentioned the positive aspects of adopting a standardized DVM reporting process and the perceived benefits of the visual elements considered in the report. Among the positive aspects of the adoption of a standard DVM report, interviewees from Case Study A listed a positive emphasis on the visualization and visual cues of the report. According to Case Study A interviewees, the report allowed for highlighting and understanding disturbances quickly and having clear frameworks for reporting and agreed reporting intervals.

Interviewees from Case Study B highlighted the benefits of standardization with the DVM system, concluding that it creates a unified manner of sharing information, increasing the focus on the information shared. In Case Study D, the interviewees affirmed that standard reporting as a DVM became the connector among project members. The established process of creating and sharing the DVM allowed earlier identification of project problems.

The value of aligning and agreeing with the standard of the DVM report at the start of the project was perceived positively in Case Studies A, B, and D. The interviewees mentioned increased clarity of communication and alignment of expectations regarding the DVM information as having improved the openness of the participants in adopting the DVM report. Across all the case studies, the interviewees mentioned that DVM adoption increased project understanding and shared SA among project participants as a result of the standardized DVM report.

In Case Study A, the DVM report was adopted by the project management team and client representatives. The interviewees referred to perceiving a higher positive impact if subcontractors and site managers also adopted such reporting. This indicates the perception that DVM adoption should also encompass the production phase of projects.

The ICT and tools enablers are summarized below:

- Positive Aspects of Standardized DVM Reporting: the positive aspects of adopting a standardized DVM reporting process and its visual elements were cross case identified.
- Alignment and Agreement: The value of agreeing on a standardized DVM report at the start of the project was positively perceived in Case Studies A, B, and D. It led to clearer communication, better alignment of expectations, and increased openness to adopting the DVM report.
- Improved Project Understanding: Across all case studies, interviewees mentioned that DVM adoption improved project understanding and created a shared SA among project participants.

- DVM adoption should extend to the production phase of projects.: In Case Study A, the DVM report was adopted by the project management team and client representatives. Interviewees believed there would be a more significant positive impact if subcontractors and site managers also adopted the reporting process.

Data Collection and Publishing Enablers

In all the case studies, the interviewees said that the adoption of DVM facilitated information sharing. It created a unified picture of the projects, enabling the distribution of information using the agreed formats and at agreed timelines.

In case studies A, B, and D, the interviewees perceived an increase in data publishing reliability after the adoption of the DVM. In Case Study A, increased data publishing reliability was associated with a contractual obligation on the adoption of the DVM report and the commitment of the project participants to publish and discuss the project status based on the KPIs shared in the DVM Report.

In Case Studies B and D, the interviewees associated the increment in data collection and publishing reliability with the adoption of a standard of the DVM report. The interviewees in case B mentioned that the adoption of the standard DVM report across the organization resulted in diminished work to produce many different reports and that having the standard DVM report allowed more effective follow-up of KPIs. In Case Study D, the interviewees mentioned that having a standard DVM report resulted in a better connection between the data collecting and sharing and the decision-making process, unifying the process of identifying the KPIs deviations and corrective actions.

Although the interviewees in Case Study C did not make direct mention of how data collecting and publishing can increase data reliability and information sharing, they mentioned that having reliable data and effective information sharing have a direct impact on the decision-making process of the project.

The data collection and publishing enablers are summarized below:

- Facilitated Information Sharing: Across all case studies, interviewees noted that DVM adoption facilitated information sharing and created a unified picture of the projects, with information being distributed using agreed formats and timelines.
- Increased Data Publishing Reliability: In Case Studies A, B, and D, interviewees observed an increase in the reliability of data publishing after adopting DVM.

People and Culture Enablers

Challenges related to *people and culture* demonstrated persistent mistrust among project members. Presently, interviewees believe that project participants are constantly trying to hide information or not disclose it completely.

On the other hand, the interviewees in all case studies perceived a correlation between the involvement and commitment of the project's stakeholders to the DVM implementation and the success of the implementation process. They also mentioned that there were attempts to implement approaches to increase stakeholders' commitment to DVM

implementation during the projects. The stakeholders' commitment creates an environment conducive to making the transition and overcoming the initial struggles.

One important approach mentioned by the Case Study B interviewees was regarding the behavior of the leadership during the project meetings and discussion of the results published in the DVM report. When the leadership maintained an environment where people felt comfortable sharing information, it resulted in increased information sharing and reduced the feeling that some information was still hidden.

The implementation of the DVM report and the discussion of the results were more positive if the focus was on solving the problems and not on finding a culprit. It also highlights an important causality between a hostile environment to share information and the consequent resistance to disclosing information.

The support and involvement of stakeholders and their approach toward the DVM implementation process seem to play a vital role in successful implementation across the project. When the leadership takes on the role of encouraging information sharing and discussion, the project team seems to be more open and honest during the project status discussions.

Another approach for encouraging information sharing was mentioned in the interviews in Case Study B. During the project status discussions, the interviewees perceived that when the leadership demonstrated interest in the information being shared, there was increased involvement of the parties in the discussions and increased clarity and openness regarding the project status.

From the interview content in all the case studies, an important aspect of Lean surfaced:

> *The mention of the need for continuous improvement in the development and adoption of the DVM report. These mentions encompass comments related to the current development of the DVM report to the need for a DVM report that is flexible and adaptable throughout the project and show both the understanding that such adoption is not static and that the development of such DVM approaches requires efforts and feedback loops.*

The people and culture enablers are summarized below:

- Stakeholder Involvement and Success: All case study interviewees noted a correlation between the commitment of stakeholders to DVM implementation and the success of the process.
- Leadership Behavior: Interviewees in Case Study B emphasized the role of leadership in creating an environment where people felt comfortable sharing information.
- Focus on Problem-Solving: DVM report implementation and discussions were more positive when the focus was on solving problems rather than finding blame.

Discussion

This study aimed to identify the barriers and enablers during the implementation of DVM in complex AEC projects. The discussion section is organized as follows: first, the identified barriers are discussed, followed by discussions regarding the enablers. The topic of maturity levels and maturity models and their impact during the implementation of DVM follows. Finally, the study limitations and possibilities for future research are discussed.

Barriers to DVM implementation

Among the identified barriers related to ICT and tools are the lack of interoperability among systems, the use of different systems for different data, and the lack of standards for information sharing. These corroborate the barriers previously discussed in Tezel et al.'s (2017) conceptual work.

When information is scattered across different systems, the increased time for reporting hinders the implementation of DVM approaches. This perception reflects DVM practices' limitations regarding their simplicity and presentation of excessive information, as well as the lack of prioritization of information (Pedó et al., 2022).

From the identified barriers to data collection and publication, the increased work for manual data collection and analysis seems to relate to the challenge of the creation and adoption of DVM devices following analog logic (Reinbold et al., 2022). Furthermore, this finding also represents the necessary non-visual work until the outcome of a visual device (Valente et al., 2018). Valente et al. (2018) proposed a model for devising VM for production management. Their study found that observing the process, analyzing user needs, and integrating the process for the creation of VM are steps needed before the visualization takes place (Valente et al., 2018).

The barriers identified under the people and culture themes emphasize trust among project members and their commitment to the implementation of the DVM. The cycle of mistrust in the AEC appears to be a barrier to the implementation of DVM applications. This mistrust was expressed as a lack of trust among project members and a lack of trust in the reported data.

Nevertheless, previous studies show evidence of the negative impacts of mistrust culture on AEC (Cheung et al., 2003; Zaghloul et al., 2003). Further studies have proposed the utilization of frameworks for creating and sustaining trust relationships in construction projects (Wong et al., 2008). The adoption of such frameworks while implementing DVM might have positive impacts on creating trust among project members and in relation to the systems utilized.

The lack of commitment of the project actors to DVM implementation was an important barrier perceived during the implementation of DVM. This barrier was previously studied as one of the challenges faced during the implementation of DVM devices, focusing on the production phase of AEC projects (Reinbold et al., 2022). These studies found that this barrier impacts both the adoption of DVM for AEC management and the DVM focusing on construction crews. On the other hand, research in the production management area associates the level of

experience with management using lean with a higher level of stakeholder engagement (Kurpjuweit et al., 2019), highlighting an important link between lean principles and success when implementing VM and DVM.

Enablers of DVM implementation

The findings of this study contribute to knowledge by identifying and revealing key factors that facilitate the implementation and adoption of DVM in complex CI projects. These enablers have not been explored in previous research. This insight opens new avenues for further exploration and provides valuable guidance for both practitioners and researchers involved in DVM and AEC initiatives.

During the case study interviews, the mention of early stakeholder involvement during the creation and standardization of the DVM report was perceived as positively impacting the other team members to engage in the process. Once a new process and a novel approach to reporting are implemented, engaging in constant work with the commitment of the parties involved, as well as taking actions to increase trust among the participants in the process of data collection and reporting, becomes essential for the successful implementation of DVM. These findings are consistent with the success factors identified in the adoption of VM in the manufacturing industry. They highlight the importance of management and employee involvement to counter resistance during the implementation of new processes (Kurpjuweit et al., 2018).

The findings also show that after the initial struggle during the initial phases of DVM implementation, the benefits of the implementation, as increased information shared and increased shared SA, were perceived by the project members, and resistance to implementation diminished. Initial struggles seem to be a normal part of implementation processes. According to our results, continuing implementation despite these initial struggles pays off. In the future, with more experience in AEC, implementation should face fewer challenges and less resistance.

Case Study B emphasizes that the leadership behavior that encouraged openness to information-sharing had a positive impact on diminishing mistrust among project members and increased the openness of project participants during information-sharing and discussion.

The adoption of a standard DVM report was perceived by interviewees as a facilitator under the topics of ICT and tools and data collection and publishing. This might be an indication that standardization was perceived as impacting positively on the work processes while also increasing the reliability of the data collected and reported.

Contracts seem to be important enablers for the adoption of DVM. There was resistance in doing extra work in Case A but they overcame the barriers because of contractual obligation. However, contractual obligation on transparency may have led to hiding of information. If other enablers are not present, contractual requirements could lead to less accurate data and more negative feedback. The importance of contracts should be further investigated in future research.

Another finding presented in all the case studies was that continuous improvement of the DVM facilitates implementation. This finding also connects to the environment that is open to information-sharing and to the contributions of the project participants. The findings also indicate that the adoption and implementation of DVM in complex AEC projects is not a one-step process but rather an incremental process that requires continuous dedication and alignment, at some level indicating a stepwise approach similar to the one reported when adopting VM in manufacturing (Kurjuweit et al., 2018).

The three facilitating factors to DVM implementation that were converging findings for all the case studies included 1) the adoption of a standardized reporting process, 2) continuous improvement during DVM adoption, and 3) the commitment of project members and project stakeholders to the implementation process. Not surprisingly, these findings are connected to important pillars of Lean Construction: respect for people, the standardization of processes, and the continuous improvement of processes (Koskela, 1992), evidence of the important connections between VM, DVM, and lean.

Maturity levels and maturity models

While analyzing the findings, the authors noticed that in Case Study B, the interviewees had more positive perceptions regarding DVM implementation. A deeper investigation of the possible reasons for the conflicting results led to the exploration of differences in the maturity levels of the teams implementing DVM.

Maturity models are used by organizations to compare their position in the competition and to identify necessary developments while offering references for improvement (de Bruin et al., 2005; Mettler, 2011). Maturity models can facilitate the more systematic implementation and spread of innovations by offering a reference framework for the various stages of development. Maturity models have also been driving development in AEC, while supporting the adoption and implementation of building information modeling (BIM) and Takt planning (Liang et al., 2016; Lehtovaara et al., 2020).

Case Study B seemed to be at a higher level of maturity in DVM implementation. In three of the projects, the interviewees reported a lack of trust in the data collection and publication process. In Case Study B, the interviewees reported that they trusted the data collection methods and the data published via DVM. This evidence of trust in data collection and publication demonstrates a more mature implementation of DVM.

In the same case study, the leadership behavior that encouraged openness to information sharing had a meaningful impact on diminishing mistrust among project members. This finding provides evidence that the trust relationships in this case were addressed effectively during the DVM implementation, pointing to a higher level of maturity in comparison to the other three case studies. These results could form a basis for developing maturity models for the adoption of DVM in complex AEC projects in future research.

Study limitations and future research

Multiple case studies as a research strategy was utilized, aiming to explore the phenomena in depth and increase the study reliability and possibilities for the generalization of the results (Eisenhardt and Graebner 2007). However, the study is geographically limited to Finland and follows a qualitative analysis, which can be affected by project participants and the researchers' biases.

To overcome geographic limitations, the study was structured in a manner that allowed it to be reproduced in different locations. The thorough documentation of the coding processes was applied by future researchers to ensure reliability and the possibility of cross-result analysis.

When conducting interviews with AEC specialists involved in DVM creation and implementation, a sample bias will be part of the study. The specialists' experience during DVM implementation, whether it was a positive or a negative experience, had a meaningful impact on how they structured their answers. Thus, the researcher concentrated on identifying the barriers and enablers during DVM implementation.

The research method chosen to analyze the interviews was the interviews transcription and open-coding according to themes, and categorization using Atlas.ti software. Other approaches to the data analysis, for example using NVivo and MAXQDA, could reduce the subjectivity inherent to this qualitative study.

The study's exploratory characteristic limits its generalizability, but it does address and provide input into the research gap related to DVM implementation. Additionally, this qualitative study was based on interviews with project professionals during the implementation of DVM. The possible quantitative analysis of documents and other project observations was not part of the study and can be addressed in future research.

Throughout the DVM implementation across all projects in this case study, no efforts were made to assess or quantify the benefits of the implementation. Future research is needed to establish methods for measuring and verifying the advantages of using standardized DVM reports. Such research could provide valuable guidance on developing standard questionnaires and KPI's to effectively assess these benefits.

Although the interviewees mentioned contractual obligations in adopting DVM, the roles and impacts of contractual models in the implementation of DVM were not the focus of the study but should be further explored. Further studies regarding maturity models for adopting VM and DVM are necessary to increase the knowledge of how maturity models can be perceived during the implementation of DVM and which role they have in the success of such implementations.

Conclusions

Digitalization in the AEC industry is increasing, and the application of digital tools as possible solutions to AEC industry problems, such as communication, project bottlenecks, and information silos, is growing rapidly. On the other hand, research on the adoption of VM and

DVM in the AEC industry is still limited. In this paper, the authors identified the barriers and enablers faced during the implementation of a DVM process when reporting different KPIs for complex infrastructure projects in Finland.

The theoretical implications of this study are that, in previous studies, the barriers to the adoption of DVM in complex AEC projects were still limited to a secondary theme on other research topics related to VM and the increase in ICT-based VM. This research addressed the barriers as a central topic, identifying them in four complex AEC projects in Finland. The theoretical contribution also addressed the gap regarding the documentation of exemplary cases adopting ICT-based VM.

This paper contributes to DVM literature by identifying and listing the key enablers for the successful implementation of DVM in case studies. Such a list has been absent in previous studies related to AEC projects, and the existing literature on similar topics within the manufacturing industry is also limited. The inclusion of these enablers offers valuable insights that can inform future research and practical applications of DVM adoption. By addressing this gap, the research provides a foundational resource for both practitioners and academics interested in enhancing DVM implementation and advancing continuous improvement initiatives.

Regarding the implications for practitioners, this research makes three recommendations:

1. Those implementing DVM should secure the involvement of project members and project stakeholders by training and coaching them in the early stages of DVM implementation, laying out the steps for adoption, the meaning of the DVM implementation, and the importance of their commitment.
2. The stakeholders and project leaders must focus on creating an environment that is welcoming to ideas and the sharing of information, even when the project faces challenges, such as delays and budget overruns, rather than targeting finding the culprits for the problems.
3. Foster and cultivate continuous improvement, encouraging the project participants to share ideas and have initiatives to improve DVM implementation. The findings of this study emphasize that the enablers of the implementation and adoption of a DVM are closely related to the concepts of Lean construction.

In addition to increasing digitalization and data-driven complex AEC projects, AEC continues to struggle with making use of the increasing amount of data. The adoption of VM and DVM practices is a step toward obtaining meaning from data and taking adequate and timely actions.

References

Akbar, A. R. N., Mohamamd, M.F., Norizan Ahmad, N., Maisyam, M., (2015). Adopting Standardization in Construction Environment: Standard Method of Measurement (SMMs), Procedia - Social and Behavioral Sciences, Volume 170, Pages 37–48, ISSN 1877-0428, https://doi.org/10.1016/j.sbspro.2015.01.013

Akinci, B. (2014). Situational Awareness in Construction and Facility Management. *Front*. Eng, 2014, 1(3): 283–289 https://doi.org/10.15302/J-FEM-2014037

Bascoul, A.M. and Tommelein, I.D. (2017). Visualizing Daily On-site Space Use In: Proc. 25th Annual Conference of the International Group for Lean Construction. Heraklion, Greece, 9–12 Jul 2017: pp. 597–604, https://doi.org/10.24928/2017/0258

Beynon-Davies, P., & Lederman, R. (2017). Making sense of visual management through affordance theory. Production Planning & Control, 28(2), 142–157.

Biotto, C., Mota, B., Araújo, L., Barbosa, G. and Andrade, F. (2014). Adapted Use of Andon in a Horizontal Residential Construction Project. In: Kalsaas, B.T., Koskela, L. and Saurin, T.A., Proc. 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25–27 Jun 2014: pp. 1295–1305.

Brandalise, F.M.P., Valente, C.P., Viana, D.D., and Formoso, C.T. (2018). "Understanding the effectiveness of Visual Management best practices in construction sites" In: Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC), González, V.A. (ed.), Chennai, India. https://doi.org/10.24928/2018/0452

Chen, Y., & Kamara, J. M. (2008). Using mobile computing for construction site information management. Engineering, Construction and Architectural Management, 15(1), 7–20. https://doi.org/10.1108/09699980810842034

Cheung S.O., T Ng T. S., Wong S. P., Suen H. C. (2003). Behavioral aspects in construction partnering, International Journal of Project Management, Volume 21, Issue 5, Pages 333-343, ISSN 0263-7863, https://doi.org/10.1016/S0263-7863(02)00052

Chi, S., and Caldas, C. H. (2011). Automated object identification using optical video cameras on construction sites. Comp. Aided Civil Infrastruct. Eng. 26, 368–80. https://doi: 10.1111/j.1467-8667.2010.00690.x

Corbin, J. M., & Strauss, A. L. (2015). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory (4th ed.). Thousand Oaks, CA: Sage publications.

Dave B., Kubler S., Främling K. and Koskela L. (2014). Addressing information flow in lean production management and control in construction, In proceedings of the 22nd annual conference of the international group for lean construction, Oslo, Norway.

Dave, B., Kubler, S., Pikas, E., Holmström, J., Singh, V., Främling, K., Koskela, L. and Peltokorpi, A. (2015). Intelligent products: shifting the production control logic in construction (with Lean and BIM). In: Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction. Perth, Australia, July 29–31, pp. 341–350.

De Bruin, T., Rosemann, M., Freeze, R., and Kaulkarni, U. (2005). "Understanding the main phases of developing a maturity assessment model." Proceedings (ACIS) Australasian Chapter of the Association for Information Systems.

Dror, E., Jianye Z., Sacks, R., Seppänen, O. (2019). Indoor Tracking of Construction Workers Using BLE: Mobile Beacons and Fixed Gatewayes vs. Fixed Beacons and Mobile Gateways. In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 831–842. https://doi.org/10.24928/2019/0154

Edwards, D. and Thomas, J. C. (2005). Developing a municipal performance measurement system: reflection on the Atlanta dashboard, Public Administration Review, 65(3), 369-76.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. Human Factors, 37(1), 65–84.

Fellows, R. F., & Liu, A. M. (2021). Research methods for construction. John Wiley & Sons, Ltd, United Kingdom.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development. *International Journal of Qualitative Methods*, 5(1), 80–92. https://doi.org/10.1177/160940690600500107

Few, S. (2005). Intelligent Dashboard Design. DM Review Magazine. United States, p. 12–14, set.

Formoso, C. T., Santos, A. D., & Powell, J. (2002). An exploratory study on the applicability of process transparency in construction sites. Journal of Construction Research, 3(1), 35–54.

Friese, S., Soratto, J., & Pires, D. (2018). Carrying out a computer-aided thematic content analysis with ATLAS.ti. *MMG Working Paper*, (18–02).

Galsworth, G. D. (1997). Visual systems: Harnessing the power of visual workplace. AMACOM: New York, NY, USA.

Gheisari, M., Irizarry, J., & Horn, D. (2010). Situation awareness approach to construction safety management improvement. In C. Egbu (Ed.), Proceedings of the 26th Annual ARCOM Conference, 6–8 September 2010, Association of Researchers in Construction Management, Leeds, UK (pp. 311–318).

Glaser, B., & Strauss, A. (1967). The Discovery of Grounded Theory: Strategies for Qualitative Research. Mill Valley, CA: Sociology Press.

Görsch, C., Seppänen, O., Peltokorpi, A., & Lavikka, R. (2020). Construction workers' situational awareness – an overlooked perspective. In I. D. Tommelein & E. Daniel (Eds.), Proceedings of the 28th Annual Conference of the International Group for Lean Construction, Berkeley, CA (pp. 937–948).

Imai, M. (1997), Gemba Kaizen: A Common-sense, Low-Cost Approach to Management, McGraw-Hill, London.

Irvine, A., Drew, P., & Sainsbury, R. (2013). 'Am I not answering your questions properly?' Clarification, adequacy, and responsiveness in semi-structured telephone and face-to-face interviews. Qualitative Research, 13(1), 87–106.

Kim, J. (2019). Automated Construction Site Monitoring: Multi Vision-Based Operational Context Analysis for Enhancing Earthmoving Productivity. Available online at: http://hdl.handle.net/10371/161874 (accessed July 2nd, 2024)

Kiviniemi, M., Charlesraj, V. C., Liinasuo, M., Siltanen, P., Rainio, K. (2024). Digital Info Screen - A Visual Management Tool for Construction Workers, Proceedings of the 41st International Symposium on Automation and Robotics in Construction, 489–496, Lille, France. https://doi.org/10.22260/ISARC2024/0064

Koskela, L. (1992). Application of the new production philosophy to construction. Technical Report. Department of Civil Engineering, Stanford University, Stanford, USA.

Koskela, L., Tezel, A. & Tzortzopoulos, P. (2018). Why Visual Management? In 26th Annual Conference of the International Group for Lean Construction, 250–260. https://doi.org/10.24928/2018/0527

Stefan Kurpjuweit S., Reinerth D., Schmidt C. G. & Wagner S. M.(2019) Implementing visual management for continuous improvement: barriers, success factors, and best

practices, International Journal of Production Research, 57:17, 5574–5588, DOI: 10.1080/00207543.2018.1553315

Lappalainen, E. M., Seppänen, O., Singh V. (2021). Transformation of construction project management toward situational awareness. Engineering, Construction and Architectural Management, 28(8), 2199–2221. https://doi.org/10.1108/ECAM-12-2020-1053

Lappalainen, E., Uusitalo, P., Seppänen, O., Peltokorpi, A., Ainamo, A., & Reinbold, A. (2024). User experiences of situational awareness systems in infrastructure construction. Construction Management and Economics, 1–14.

Lehtovaara, J., Heinonen, A., Lavikka, R., Ronkainen, M., Kujansuu, P., Ruohomäki, A., Örmä, M., Seppänen, O., and Peltokorpi, A. (2020). "Takt Maturity Model: From Individual Successes Towards Systemic Change in Finland." In: Tommelein, I.D. and Daniel, E. (eds.). Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28), Berkeley, California, USA, doi.org/10.24928/2020/0017

Li, X., Yi, W., Chi, H. L., Wang, X., & Chan, A. P. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Automation in Construction, 86, 150–162.

Liker, J. (1997). Becoming Lean: Inside stories of US manufacturers. Productivity Press, Portland, OR.

Memarzadeh, M., Golparvar-Fard, M., and Niebles, J. C. (2013). Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors. Automat. Constr. 32, 24–37. http://doi:10.1016/j.autcon.2012.12.002

Mettler, T. (2011). "Maturity assessment models: a design science research approach." International Journal of Society Systems Science (IJSSS), 3(1/2).

Middleton, A. (2005). By the Dashboard Light. Marketing, Toronto, vol. 10, iss.15, p.14, 2 p., apr. 2005.

Moore, G. H. (Ed.) (1983). The forty-second anniversary of the leading indicators. In Business cycles, inflation, and forecasting (2nd ed., pp. 369–400). Ballinger.

Olivieri, H., Seppänen, O., & Peltokorpi, A. (2017). Real-time tracking of production control: Requirements and solutions. In Proceedings of the 25th Annual Conference of the International Group for Lean Construction, Heraklion, Greece (pp. 671–678).

Pedó, B., Formoso, C. T., Viana, D. D., Tzortzopoulos, P., Brandalise, F. M. P., & Whitelock-Wainwright, A. (2022). Visual management requirements to support design planning and control within digital contexts. Sustainability, 4(17), 10989. https://doi.org/10.3390/su141710989

Pica, D., & Abanda, F. H. (2019). Emerging BIM-3D-laser scanning integration in construction practice. In Proceedings of the 11th International Conference CITC-11, London, UK.

Reinbold, A., Lappalainen, E., Seppänen, O., Peltokorpi, A., & Singh, V. (2022). Current challenges in the adoption of digital visual management at construction sites: Exploratory case studies. Sustainability, 14(21), 14395. https://doi.org/10.3390/su142114395

Reinbold, A., Seppänen, O., Peltokorpi, A., Singh, V., & Dror, E. (2019). Integrating indoor positioning systems and BIM to improve situational awareness. In Proceedings of the 27th Annual Conference of the International Group for Lean Construction, Dublin, Ireland, 1141–1150.

Sacks R., Koskela L., Dave B.A. and Owen R. (2010). Interaction of lean and building information modelling in construction, Journal of Construction Engineering and Management, Vol. 136, No. 9, 968–980.

Seppänen, O., & Peltokorpi, A. (2016). A new model for construction material logistics: From local optimization of logistics towards global optimization of on-site production system. In Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, MA.

Shermach, K. (2005). Driving performance. Sales and Marketing Management. p. 18, dez. 2005.

Shibeika, A., & Harty, C. (2015). Diffusion of digital innovation in construction: A case study of a UK engineering firm. Construction Management and Economics, 33(5–6), 453–466.

Shingo, S. (1989). A Study of the Toyota Production System from an Industrial Engineering Viewpoint. Productivity Press, Portland.

Soman, R. K., & Whyte, J. K. (2020). Codification challenges for data science in construction. Journal of Construction Engineering and Management, 146(7), 04020072.

Sugimori, Y.K., Kusunoki, K., Cho, F. and Uchikawa, S. (1977). "Toyota Production System and Kanban System: Materialization of Just-in-Time and Respect-for-Human System," International Journal of Production Research, 15(6): 553–564.

Tetik, M., Peltokorpi, A., Seppänen, O., Leväniemi, M., & Holmström, J. (2020). Kitting logistics solution for improving on-site work performance in construction projects. Journal of Construction Engineering and Management, 147(1), 05020020.

Tezel, A., Koskela, L. and Tzortzopoulos, P. (2009). "The Functions of Visual Management." International Research Symposium, Salford, UK.

Tezel, A. (2011). Visual management: An exploration of the concept and its implementation in construction. PhD dissertation, University of Salford.

Tezel A., Koskela L., Tzortzopoulos P., Formoso C.T. and Alves T. (2015). Visual management in Brazilian construction companies: taxonomy and guidelines for implementation, Journal of Management in Engineering, Vol. 31, No. 6, 05015001.

Tezel, A. & Aziz, Z. (2017). From conventional to IT-based visual management: A conceptual discussion for lean construction. Journal of Information Technology in Construction (ITcon), Vol. 22, pg. 220-246, http://www.itcon.org/2017/12

Turk, Ž. (2020). Interoperability in construction – Mission impossible? Developments in the Built Environment, 4, 100018.

Vaismoradi, Mojtaba & Snelgrove, Sherrill (2019). Theme in Qualitative Content Analysis and Thematic Analysis [25 paragraphs]. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *20*(3), Art. 23, http://dx.doi.org/10.17169/fqs-20.3.3376.

Yang, J., Park, M. W., Vela, P. A., and Golparvar-Fard, M. (2015). Construction performance monitoring via still images, time-lapse photos, and video streams: now, tomorrow, and the future. Adv. Eng. Inform. 29, 211–224. https://doi:10.1016/j.aei.2015.01.011

Yin, R. K. (2018). Case study research and applications (Vol. 6). Thousand Oaks, California: Sage.

Williams, M., & Moser, T. (2019). The Art of Coding and Thematic Exploration in Qualitative Research. *International Management Review, 15*, 45.

Wong W. K., Cheung S. O., You T. W., Pang H. Y. (2008). A framework for trust in construction contracting, International Journal of Project Management, Volume 26, Issue 8, Pages 821–829, ISSN 0263-7863, https://doi.org/10.1016/j.ijproman.2007.11.004

Zaghloul R., Hartman F., (2003). Construction contracts: the cost of mistrust, International Journal of Project Management, Volume 21, Issue 6, Pages 419–424, ISSN 0263-7863, https://doi.org/10.1016/S0263-7863(02)00082-0.

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