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SIMULATION TO BRIDGE THE GAP BETWEEN VISUAL MANAGEMENT THEORY AND ON-SITE APPLICATIONS

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ABSTRACT

This study examines the effectiveness of Visual Management (VM), a Lean Construction tool, in reducing stress levels and improving efficiency in construction processes. Through a simulated floor plan modification exercise, we compare the performance of teams using traditional written instructions versus those employing VM techniques. The research aims to quantify the time savings and accuracy improvements achieved by using visual tools such as shadow marking and color coding. The methodology involves a crossover design with a total of 64 students, participating in both Lean and Non-Lean conditions across two rounds. Performance metrics include accuracy (the number of tasks accurately completed) and stress levels. Our findings demonstrate that VM significantly reduces task completion time, enhances accuracy, and decreases stress levels in a simulated construction-like environment. This study contributes to the growing body of evidence supporting the implementation of Lean principles, particularly VM, in construction projects to enhance productivity and reduce waste.

KEYWORDS

Visual management, productivity, accuracy improvement, lean simulation, stress reduction.

INTRODUCTION

Visual Management (VM) has emerged as a fundamental strategy in lean construction, enhancing process transparency and information accessibility in construction environments (Valente et al. 2017). VM manifests through various tools and practices designed to optimize information flow and reduce cognitive processing demands (Valente et al. 2017). Tezel et al. (2013) demonstrated that VM implementation in industrial construction improved production control through physical visualization boards, enhancing work sequencing, crew coordination, and cross-team communication while reducing process variability by 32% compared to conventional methods.

Visual Management (VM) extends beyond visualization as a collaborative, transparent management philosophy. Tommelein et al. (2024) emphasized that VM must integrated with broader management systems, with effectiveness varying significantly based on project context

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and complexity. Formoso et al. (2002) demonstrated 18–22% waste reduction using 10 measurable indicators due to process transparency strategies.

However, existing studies lack empirical validation across diverse contexts. Many studies focus on conceptual frameworks over practical testing, limiting real-world applicability and hindering solutions for project complexity and stakeholder communication variability. Gaps persist in connecting VM purposes (e.g., continuous improvement, job facilitation, etc.) and developing flexible information-display models for adaptive implementation.

Construction projects face inherent challenges due to their complex nature and susceptibility to uncertainty. Recent systematic reviews emphasize that integrating Lean Construction with buffer management is essential for addressing workflow variability and improving project performance (Abuelaish & Toğan, 2024), requiring careful consideration of flexibility and adaptation to different project contexts (Tommelein 2017). The objective of this research is to empirically evaluate the effectiveness of Visual Management (VM) tools in improving process transparency and performance in simulated construction tasks.

The relationship between VM and project performance has become well-documented through empirical research. Studies demonstrate that effective VM implementation significantly impacts project outcomes (Formoso & Moura 2009), with recent work emphasizing time-cost trade-offs in planning processes (Tommelein 2024). The educational aspect has evolved toward systematic learning approaches, with research indicating that collaborative environments are essential for successful VM adoption (Tommelein et al. 2024).

Recent case studies have further demonstrated the global applicability of Lean Construction principles. Aisyah et al. (2023) explored the implementation of Lean Construction through the Waste Register Method in Indonesian projects, highlighting the adaptability of these principles across diverse contexts.

In the context of continuous improvement, VM serves as both a measurement tool and catalyst for organizational change. Research emphasizes the importance of integrating production and quality control systems (Fireman & Formoso 2013), supporting effective resource allocation and complexity management in construction projects (Tommelein 2024).

LIMITATIONS IN EXISTING CONSTRUCTION SIMULATIONS

Previous construction education simulations have primarily focused on traditional project management aspects such as scheduling and resource optimization (Tommelein 1998; Tommelein et al. 1999), often neglecting the critical role of visual communication in construction processes (Tezel et al. 2016). While effective for teaching basic management concepts, these tools emphasize theoretical frameworks over practical visualization aspects and their measurable impact on task execution (Brady et al. 2018). This gap is particularly significant given the industry's increasing reliance on visual management for complex process coordination (Tezel & Aziz 2017). Experimental learning has transformed this educational landscape by providing dynamic, hands-on experience through realistic simulations that mirror actual construction challenges (Bhatnagar et al. 2022). This approach moves beyond traditional instruction by engaging students in practical problem-solving with immediate feedback (Dave et al. 2008), allowing them to actively apply and test theoretical concepts. The methodology proves especially effective for teaching complex concepts such as Visual Management, where practical application substantially enhances understanding compared to theoretical instruction alone (Koskela et al. 2018).

RESEARCH GAP IN VISUAL MANAGEMENT STUDIES

Prior research has demonstrated the positive impact of Visual Management (VM) when applied to construction projects (Brandalise et al. 2021). That said, there is still a need to scientifically test and quantify VM's impact using controlled experimentation. While VM offers significant potential for improving process transparency and communication, empirical validation remains limited. The purpose of this preliminary study is to help fill this gap.

METHODOLOGY

Our research addresses a potential gap between theory and practice through a methodologically rigorous approach, employing a controlled simulation study that directly compares traditional written instruction methods with Visual Management techniques. A crossover design, involving 64 participants responding to both traditional management and VM management practices, enables the collection of metrics including task completion rates, accuracy scores, and stress levels. The experimental design incorporates structured stages with a 6-minute time limit for 25 tasks in each round, allowing for performance comparisons. This systematic approach not only provides preliminary empirical validation of Visual Management benefits but also establishes a quantifiable framework for measuring its impact on construction task execution. Data were obtained from a sample of 64 participants in the United States and India, ensuring geographic diversity in the analysis of VM in construction.

While the crossover design controls for individual variability, potential learning effects between rounds were acknowledged through analysis of performance pattern variations across trial sequences. It is important to acknowledge the potential for learning effects between simulation rounds. As participants complete the first round, they may become more familiar with the task structure and requirements, potentially influencing their performance in the second round. This familiarity could lead to improved performance regardless of the intervention (VM techniques) and should be considered when interpreting the results. Future studies may consider incorporating counterbalancing or more extensive training periods to mitigate these potential learning effects.

EXPERIMENTAL DESIGN

The simulation was conducted digitally, giving each participant access to their own set of Google Slides™ which they could manipulate using their laptops or iPads™. The participants were enrolled graduate students in lean construction courses in two different universities in two different countries. In the Texas A&M University, a US-based university, data was collected during two sessions. In the CEPT University, an India-based university, data was collected during one session. Both sessions were conducted within one hour. Simulation pieces were all digital and participants were given access using both a dedicated QR code or hyperlink to a Google Drive™. Each participant had access to his or her own set of Google Slides. The study identified two accessibility limitations: iPad users experienced interface challenges with touch-based manipulation of digital elements, particularly during precise placement tasks, and the color-coding system used in the experimental round did not meet Americans with Disabilities Act (ADA) compliance standards, relying solely on hue differentiation without supplemental patterns or labels. These factors may have influenced participant performance and should inform future implementations requiring device-agnostic interfaces and ADA compliant visual schemes. The simulation followed a structured staged process designed to maximize data reliability and experimental validity, comparing traditional and VM approaches as follows:

Round 1: Control Group representing traditional practice:

1. Explanatory introduction to participants

The facilitator gave a comprehensive introduction to floor plan modification tasks, followed by a verbal "walkthrough" with participants of a typical residential floor plan (Figure 1). The facilitator then provided participants with an explanation of performance metrics and evaluation criteria. Participants also received brief training on tool usage and modification techniques to ensure they were adequately prepared for the simulation.

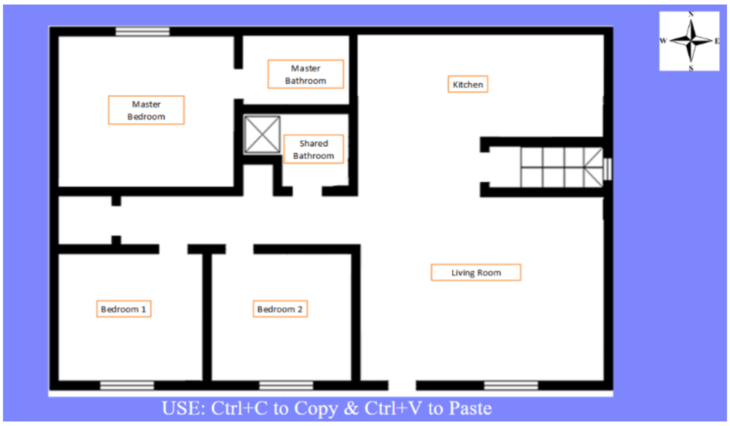

Figure 1: Round 01—Plan with typical floor-plan features (Control Round)

2. Execution Phase

In the Execution Phase, participants were given a 6-minute time limit to complete 25 tasks. They were provided with access to a text-based task list for element placement (Figure 2), along with an architectural elements list (Figure 3) to guide their work during this timed session.

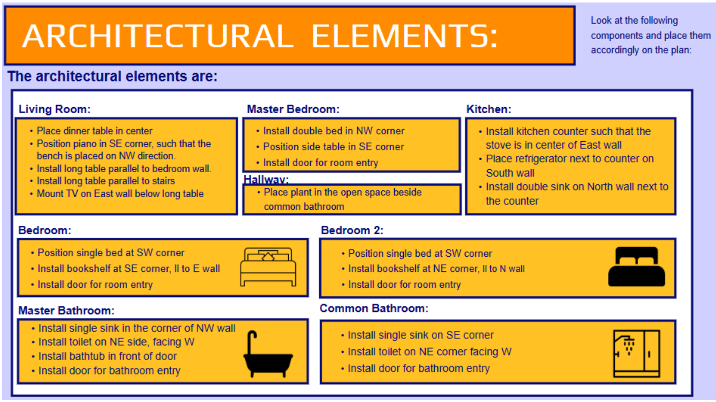

Figure 2: Tasks list to be completed.

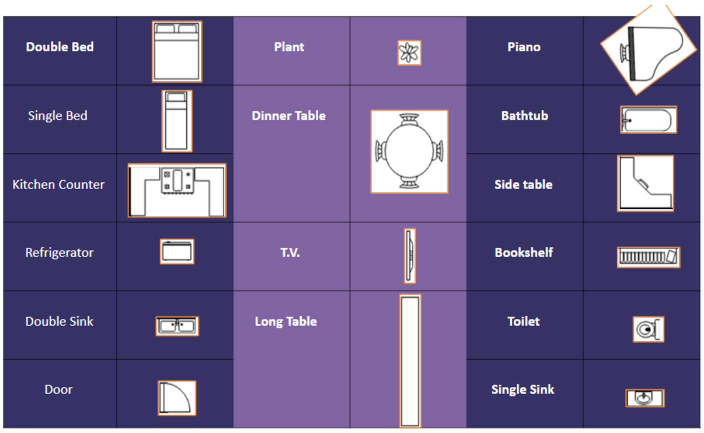

Figure 3: Architectural elements.

3. Assessment Phase

During the Assessment Phase, participants performed a self-evaluation using the provided solution plan (Figure 4) to compare their results against the desired arrangement. They then documented their performance using Google Forms™, ensuring a structured and consistent method for recording, and analyzing their outcomes.

The Google Form captured the following data: the participant's name, the number of tasks completed within the specified time (with correct locations as shown in the provided drawing), and a self-reported stress level rated on a scale from 1 to 10.

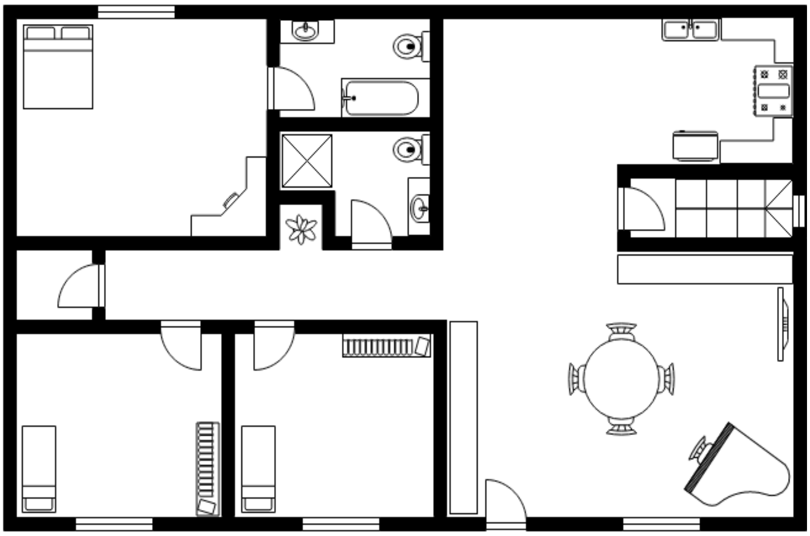

Figure 4: Desired arrangement.

Round 2: Experimental Group representing inclusion of VM techniques:

1. Enhanced Setup

Participants were given access to a similar floor plan as they were given in Round 1. However, shadow markings were included for element placement. Instead of text, a color-coding system was used for room identification (Figure 5).

Figure 5: Round 2—VM floor plan slide (Experimental Round)

2. Execution Phase

Each participant was given a 6-minute time limit to complete 25 tasks.

3. Assessment Phase

During the Assessment Phase, participants first performed self-evaluation using the provided solution plan. They then documented their performance using Google Forms™. The Google Form in Round 2 was similar to that used in Round 1, containing the same questions regarding the number of tasks completed and stress level. However, it included one additional question: “How do you think Visual Management can help during construction? Brainstorm some examples.”

The facilitator shared a spreadsheet of participant results, followed by a debriefing session where participants were invited to share their thoughts on the simulation's purpose and brainstorm applications of Visual Management to improve performance on actual job sites.

PERFORMANCE METRICS AND ASSESSMENT

The study measured two performance indicators (Table 1):

1. Accuracy scores were represented by the number of placements successfully completed (1 point for accurate placement, 0 points for inaccurate placement)
2. Stress levels were self-reported by participants according to standardized ratings (1-10; 1 indicating minimal stress and 10 indicating severe stress)

Table 1: Performance Metrics and Measurement Methods in VM Implementation Study:

Metrics	Measurement Tool	Unit
Completion Time	Stopwatch	Seconds
Accuracy	Count	Score
Stress Levels	Google Form	Scale Rating

SCORING SYSTEM

Accuracy scoring employed a binary system. Participants were asked to give themselves a score of 1 point for correct location and orientation and 0 points for any deviation, reflecting the construction’s typical tolerance requirements for equipment and structural placement. Stress levels, reported via a 0-10 scale in Google Forms, captured cognitive loading during task execution, simulating high-pressure scenarios such as sudden schedule compression.

RESULTS AND DATA ANALYSIS

DATA ANALYSIS FRAMEWORK

Statistical analysis of 64 participants across two experimental phases demonstrated significant improvements in Visual Management effectiveness are done further along with this paper; the results from completed tasks and stress levels in both rounds are summarized in Table 2. Tallies / descriptive statistics of the data in table 2. are presented in Table 3.

Key patterns emerged:

- In the VM conditions, the mode for tasks completed per session shifted from 9 to 25.
- Stress reduction mode shifted from 7 to 1 on the 10-point scale.

While the overall trends show significant improvements with VM implementation, the data reveals considerable variability in individual responses.

Table 2: Results from Completed Tasks and Stress Levels in Both Rounds

No.	Tasks R 1	Tasks R 2	% Change	Stress R 1	Stress R 2	% Δ	No.	Tasks R 1	Tasks R 2	% Change	Stress R 1	Stress R 2	% Δ
1	6	12	**100**	10	1	**-90**	33	10	18	**80**	6	4	**-33**
2	9	25	**178**	6	3	**-50**	34	18	21	**17**	7	4	**-43**
3	14	25	**79**	6	3	**-50**	35	24	24	**0**	5	2	**-60**
4	8	23	**188**	9	7	**-22**	36	20	26	**30**	7	5	**-29**
5	10	25	**150**	6	7	**17**	37	19	15	**-21**	5	2	**-60**
6	11	18	**64**	5	3	**-40**	38	12	14	**17**	7	5	**-29**
7	13	21	**62**	7	4	**-43**	39	8	14	**75**	7	5	**-29**
8	19	25	**32**	6	3	**-50**	40	16	20	**25**	5	7	**40**
9	4	15	**275**	5	4	**-20**	41	12	24	**100**	1	1	**0**
10	15	20	**33**	5	4	**-20**	42	19	15	**-21**	7	1	**-86**
11	9	25	**178**	6	4	**-33**	43	17	27	**59**	3	2	**-33**
12	8	20	**150**	7	1	**-86**	44	22	27	**23**	2	1	**-50**
13	9	16	**78**	3	3	**0**	45	22	25	**14**	3	4	**33**
14	9	14	**56**	3	1	**-67**	46	19	22	**16**	3	1	**-67**
15	17	25	**47**	9	1	**-89**	47	16	18	**13**	6	6	**0**
16	10	15	**50**	8	7	**-13**	48	12	20	**67**	1	1	**0**
17	12	22	**83**	3	1	**-67**	49	18	25	**39**	1	1	**0**
18	5	15	**200**	1	1	**0**	50	9	11	**22**	7	3	**-57**
19	10	19	**90**	6	5	**-17**	51	12	16	**33**	4	4	**0**
20	5	20	**300**	8	3	**-63**	52	26	27	**4**	1	1	**0**
21	6	10	**67**	3	4	**33**	53	7	11	**57**	10	6	**-40**
22	7	17	**143**	10	5	**-50**	54	20	27	**35**	6	5	**-17**
23	10	25	**150**	10	7	**-30**	55	14	9	**-36**	7	5	**-29**
24	6	24	**300**	7	4	**-43**	56	16	24	**50**	1	4	**300**
25	11	21	**91**	7	4	**-43**	57	4	5	**25**	3	2	**-33**
26	11	23	**109**	7	6	**-14**	58	22	26	**18**	2	2	**0**
27	20	25	**25**	6	2	**-67**	59	8	19	**138**	8	3	**-63**
28	7	18	**157**	5	2	**-60**	60	9	7	**-22**	3	4	**33**
29	5	21	**320**	9	7	**-22**	61	26	25	**-4**	5	8	**60**
30	6	22	**267**	6	3	**-50**	62	9	20	**122**	7	7	**0**
31	9	21	**133**	8	4	**-50**	63	19	19	**0**	2	1	**-50**
32	8	17	**113**	7	6	**-14**	64	22	19	**-14**	4	3	**-25**

This variability may be attributed to factors such as individual learning styles, prior experience with visual tools, or varying levels of adaptability to new methodologies. Some participants showed dramatic improvements, suggesting a strong affinity for visual learning, while others experienced minimal change or even slight decreases in performance. This heterogeneity in responses underscores the importance of considering individual differences when implementing VM strategies in real- world construction settings.

These results highlight VM's potential to enhance construction task efficiency while reducing cognitive load, though individual responses showed substantial variability. The data underscores the need for adaptable implementation strategies to maximize VM benefits across diverse workforce capabilities. Descriptive statistics for participant performance are presented in Table 3.

Table 3: Descriptive Statistics

	Tasks		%	Stress		%
	R 1	R 2	Change	R 1	R 2	Change
Mean	13	20	54	5	4	-20
SD	6	5	-17	3	2	-33
Median	11	20	82	6	4	-33
Mode	9	25	178	7	1	-86

These results are made visually clear when plotted, though with notable individual variations in both performance and stress responses. Task completion improvement by “workers” (participants) is shown in Figure 6 and stress reduction in Figure 7.

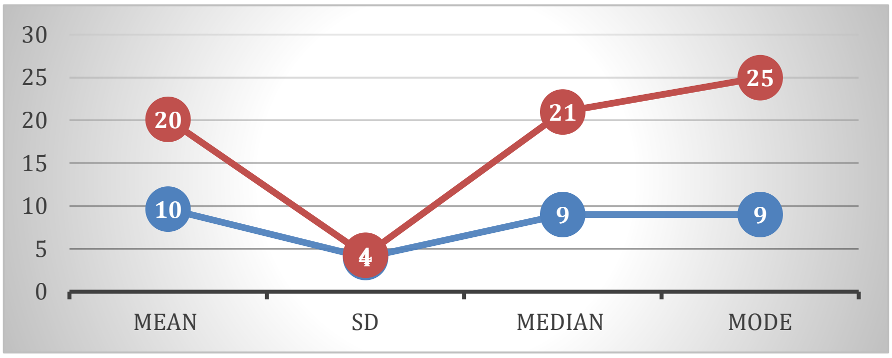

Figure 6: Stats of participant self-reporting of Tasks Completed from (0-25) Control Group (blue) vs. Experimental Group (red).

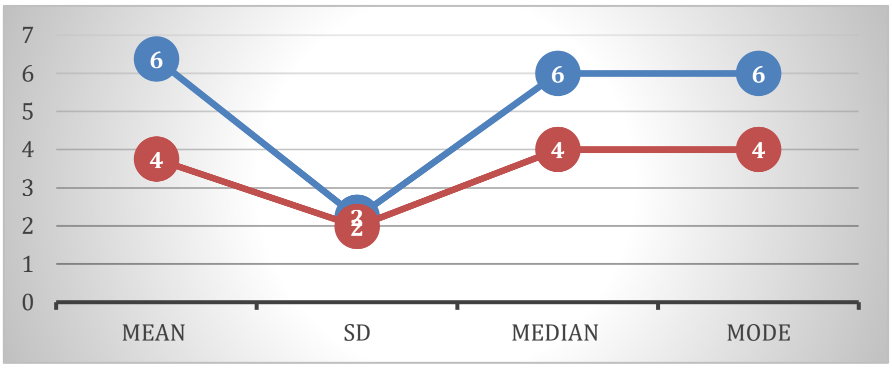

Figure 7: Participant self-reporting of stress levels from 0 (lowest) to 10 (highest) Control Group (blue) vs. Experimental Group (red).

DISCUSSION

Visual Management implementation offers numerous benefits across various construction operations. In field operations, it significantly reduces trade miscommunication, enhances sequence understanding, enables faster on-site decision-making, and minimizes rework requirements. The methodology proves highly adaptable for training applications, effectively supporting worker orientation, safety protocols, operating procedures, and cross-cultural communication. In project management contexts, VM demonstrates substantial value by improving subcontractor coordination, optimizing resource allocation, enhancing progress monitoring capabilities, strengthening quality control measures, and facilitating better risk communication. Collectively, these diverse applications highlight Visual Management's significant potential in enhancing construction project efficiency and minimizing operational waste, leading to considerable performance improvements and waste reduction in actual construction operations.

Following execution of the simulation, it is important to discuss with participants potential applications of VM to processes within the construction industry. VM applications in construction span multiple areas such as MEP coordination through BIM clash detection which provides immediate feedback for modifications. For example, time management can be improved by tracking task durations for workflow optimization, quality control systems can verify installations against specified tolerances, and color coding can be used to visually communicate task status or completion to project teams. For example, as observed at Akron Children’s Hospital, a color-coding system rapidly communicated to successive trade partners when a task was completed, quickly signalling readiness for the next trade partner to begin. This is shown in Figure 8 where yellow represents completion of studs.

Figure 8: Color-coded visual management system on metal studs indicating completion status of different trade work (Akron Children’s hospital). Photo by Z. K. Rybkowski.

Purple for completion of plumbing/HVAC, pink for completion of insulation and caulking, orange for completion of electrical, blue for completion of blocking, and green for final check/approval. Visual Management's benefits align closely with Lean Construction principles. Improved task completion rates and reduced stress reflect waste reduction and continuous flow concepts. VM enhances information accessibility, supporting transparency and enabling faster decision- making. The color-coding system exemplifies visual controls for streamlined processes. These findings reinforce VM as a key enabler of Lean Construction, improving efficiency, reducing variability, and enhancing collaboration.

LIMITATIONS

One limitation of this study included the tools used by the students since some arrived in class with laptops and mice, while a few used iPads. The facilitators discovered that those who used iPads had difficulty manipulating the games pieces; consequently, some performed more poorly during Round 2. Also, as one participant noted, the color-coding was not ADA compliant, suggesting that this would need to be taken into consideration during the further development of the simulation. Finally, despite demonstrating significant improvements in task completion and stress reduction, with individual gains up to 300%, the research has notable limitations in terms of external validity. The controlled environment with 64 student participants may not fully represent construction site complexities, and the focus on specific floor plan modification tasks may not encompass VM's broader applications. However, consistent performance patterns support methodological reliability.

CONCLUSION

This study aimed to capture measurable evidence of Visual Management's (VM) effectiveness in construction environments, focusing on time efficiency, task accuracy, and stress reduction. By bridging theoretical concepts with practical applications, the research developed implementation guidelines and performance metrics for industry-wide use.

A controlled simulation of 64 participants demonstrated a significant impact of VM, with mean task completion rates increasing from 13 to 20 tasks and stress levels decreasing from a mean of 5 to 4 on a 10-point scale. The mode of task completion improved from 9 tasks in Round 1 to 25 in Round 2.

Despite its contributions, the study's limitations include the controlled environment, student participant pool, and short duration. Future research should validate these findings in real-world construction settings through longitudinal studies, comparative analyses of VM tools, and evaluations of VM's role in safety, communication, and lean principles. These efforts would bridge simulation and practice, advancing effective VM implementation across the industry.

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