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SIMULATION AND GAMIFICATION IN LEAN CONSTRUCTION: AN OVERVIEW OF CURRENT APPLICATIONS AND INTEGRATION OPPORTUNITIES

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ABSTRACT

The construction industry faces persistent challenges, including inefficiencies, schedule delays, and high injury rates, despite advancements in digital technologies. While simulation and gamification approaches have shown promise in improving efficiency, safety, and collaboration, their integration within lean construction remains unexplored. This study systematically explores the application and integration of these methods, focusing on practical implementation. Using PRISMA 2020 and Scopus as the primary guide and database, an extensive screening process with defined criteria was conducted. Through content analysis, key themes were developed to categorise approaches and their integration. Findings show widespread use of Discrete Event Simulation (DES) and Building Information Modelling (BIM), while digital twin technologies remain underutilised, and gamification remains limited to pedagogical environments. Integrating simulation tools with lean principles like takt planning and the Last Planner System (LPS) demonstrates transformative potential for time conservation and enhanced project outcomes. A social network analysis (SNA) was employed to explore relationships between fifteen lean construction principles and thirty-five simulation approaches. This revealed key links that enhance collaboration and workflow efficiency. The study highlights the importance human-centric considerations and industry-academia collaboration to overcome barriers and accelerate digital transformation, suggesting opportunities for better integration of simulation and gamification methods.

KEYWORDS

Lean construction, simulation, gamification, real-scenario implementation, integration.

INTRODUCTION

The construction industry has been extensively reviewed for digital technology advancement and implementation (Dobrucali et al., 2024; Piras et al., 2024). These technologies aim to modernise construction processes by addressing persistent challenges such as high injury rates, normalised schedule delays, and inefficiencies in management, planning, and collaboration (Akindele et al., 2024; Clavel et al., 2024). Despite evidence demonstrating their benefits,

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adoption remains limited due to resistance to change, high subscription costs, and the time-intensive learning curve required for new technologies (Piras et al., 2024)

Lean philosophy focuses on eliminating waste, enhancing value, and continuously improving processes, driving efficiency, collaboration, and streamlined workflows in construction (Tommelein, 1997). This aligns with digital tools like simulation and gamification, which offer predictive modelling to improve decision-making (Shehab et al., 2020) and apply gaming concepts to boost engagement (Oke et al., 2024). These tools hold great potential for transforming lean construction practices (Ilbeigi et al., 2023; Liu et al., 2020), though their adoption remains limited, revealing a gap between theory and practical use.

This study explores the integration of simulation within lean construction projects while acknowledging the potential of gamification with a similar progression, hence assessing both progress and barriers to adoption. Furthermore, this research focuses on practical industry applications rather than pedagogical frameworks. Given that gamification remains largely underutilised outside educational settings (Ilbeigi et al., 2023; Oke et al., 2024), this study primarily examines simulation approaches while acknowledging gamification's potential for enhancing lean construction methodologies (Pütz et al., 2021). This is explored in Arefazar and Rybkowski (2022) study for further developing simulation games to teach Value Stream Mapping (VSM) which is a lean approach to enhance management practices in a visually structured process. Similarly, Liu et al. (2020) directs attention towards utilising serious games for a more engaging approach to implementing the Last Planner System (LPS) during the project phases which require the most collaboration between multi-disciplinary personnel such as the design phases and on-site construction. Moreover, Forcael et al. (2024) focused their research on teaching Program Evaluation and Review Technique (PERT). They successfully ensured positive results such as higher test scores and greater understanding from engineering students with the implementation of gaming theory in this pedagogical approach.

A key assumption of this research is that gamification approaches utilise simulated tools, particularly in lean construction strategies such as the previously mentioned VSM (Arefazar & Rybkowski, 2022), LPS (Liu et al., 2020), and PERT (Forcael et al., 2024). This is due to the pattern of digitised serious games, which considers how gamification is still developing. Moreover, its integration with simulation has the potential to reshape industry perspectives and improve engagement with digital tools (Alves et al., 2022; Jacobsen et al., 2021; Stevens & Poshdar, 2024).

Therefore, revealing opportunities to support the digital transformation of the construction industry by identifying which approaches are well-integrated with lean construction and which remain underutilised. Moreover, it informs the development of targeted interventions, ensuring that digital approaches align with lean construction goals to improve efficiency, collaboration, and waste reduction. To guide this review, the research is centred around addressing the following questions:

- What are the current trends in the application of simulation and gamification methods within the construction industry?
- How do existing simulation and gamification approaches contribute to implementing real scenarios in lean construction projects?
- What potential synergies exist between the practical approaches of simulation methods that could enhance decision-making and scenario implementation in lean construction?

Ultimately, by concentrating on methodologies employed in action research that directly engage with industry, the study ensures relevance to real-world implications. Two main requirements are developed to define this scope: (1) independent simulation or gamification methods must provide practical insights and demonstrated benefits as independent approaches, or (2) integrated models of simulation and gamification either with other technologies, lean principles recognised by industry professionals, or common management practices. However, these must have progressed beyond theoretical development to demonstrate use in real-world lean construction projects.

The subsequent sections of this paper are as follows: (1) A Literature Review that encompasses a concise overview of simulation and gamification methods. (2) Method of Research, which complies with PRISMA 2020 for a comprehensive screening process and content analysis. (3) A social network analysis that utilises Python and NVivo to effectively create visual representations of the links between simulation and gamification approaches with lean principles. (4) Findings and Discussion section evaluates discoveries and effectively explores the potential integration of digitalisation and lean principles in the construction industry. (5) The Conclusion summarise the research goals, highlights limitations, and suggestions for future work.

LITERATURE REVIEW

SIMULATION METHODS

Simulation involves a broad category of applications in the digital world that replicate or approximate real-world environments, often utilising multi-dimensional displays or computational models to analyse, predict, or optimise processes (Shannon, 1992). The early development of simulation has paved the way for current industries to leverage its mimicry, representing a modern approach to utilising existing and emerging technologies for effective visualisation of predictive measures and supporting human decision-making. BIM exemplifies the critical benefits and optimal utilisation of modelling predictive or existing systems, buildings, and processes (Farouk & Rahman, 2023). Another increasingly used application is Discrete Event Simulation (DES) which models where events occur at specific times optimising processes such as manufacturing and logistics (Abbasi et al., 2020). Tommelein (1997) demonstrated the value of discrete-event simulation (DES) in modelling lean construction principles such as waste reduction, uncertainty management, and flow optimisation. Using examples like pipe spool installation and concrete placement, the study illustrated how DES uncovers inefficiencies and enables the redesign of construction processes to reduce waste and improve performance. This foundational work established DES as a key tool for advancing lean principles in construction contexts. According to Piras et al. (2024), quality of data and expertise remain challenges, however, advancements in Artificial Intelligence (AI) and cloud computing are enhancing the accessibility and efficiency of these technologies. Moreover, human-centric design continues to improve usability, enabling stakeholders to effectively pursue sustainable goals within the built environment (Goh & Chong, 2023). Simulation approaches are revolutionising the construction industry by tackling challenges related to cost, efficiency, and stakeholder collaboration. As simulation technology evolves, its capacity to reshape construction practices and drive innovative solutions steadily increases.

GAMIFICATION METHODS

In 2002, Nick Pelling pioneered gamification, which gained prominence in marketing and education, demonstrating its effectiveness in enhancing participation and enthusiasm (Sharma & Sharma, 2023). According to Clavel et al. (2024); Oke et al. (2024), the key concept of gamification is its purpose-driven nature, in which applies game elements such as advancement rewards, challenging levels, and progress tracking into a work or training environment; ultimately, gamification enhances engagement and learning. It has shown particular promise and popularity in the construction sector as a way to solve leading problems including high injury rates through an innovative method for health and safety training(Akindele et al., 2024; Aliu et al., 2023). However, the lack of adoption of this theoretical framework contributes heavily to its underdeveloped application. Nevertheless, Arefazar and Rybkowski (2022) highlighted the potential of integrating gamification approaches with lean construction principles, such as their VSM tool, to intuitively teach lean principles and waste identification to construction professionals. Their work illustrates how engaging, scenario-based learning fosters better understanding and application of lean principles. Therefore, revealing the potential of gamification to provide an effective strategy to address these issues, especially with advancements in technology.

METHOD OF RESEARCH

SYSTEMATIC LITERATURE REVIEW

Following the structured methodology outlined from PRISMA 2020, this comprehensive review involved multiple phases of data collection and screening. Scopus was employed as the primary data source, Rayyan was selected as the primary screening tool and NVivo was employed for content analysis. The initial pool of documents was further narrowed through rigorous inclusion and exclusion criteria. Moreover, an effective data collection approach involved the use of (1) Boolean operators such as AND and OR between search terms, and (2) truncation techniques, including quotation marks for multi-word phrases and asterisks for word variations (Kalvik, 2024). For instance, the use of simulat* captured terms such as simulate, simulates, simulated, simulation, and simulating.

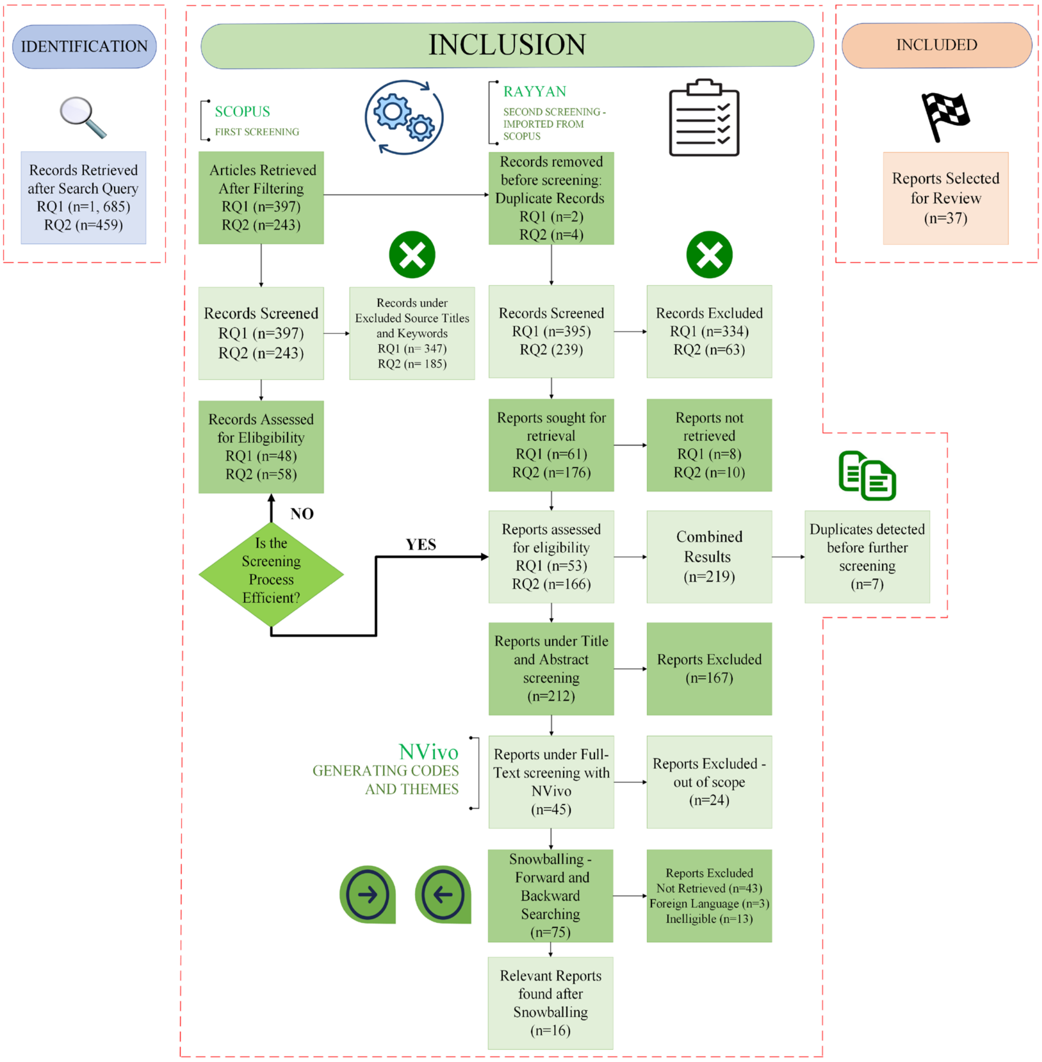

Figure 1: Flow Diagram of Literature Retrieval Process

DATA COLLECTION

To retrieve high-quality results from Scopus, the search phrase needed to effectively capture concepts relevant to addressing the research questions. For example, the relevant concepts for RQ1 were (1) Lean Construction, (2) Simulation Methods, (3) Gamification Methods which can be seen in Table 1. Under these headings, a list of synonymous words or ideas relating to it were identified to assist in identifying relevant documents for review.

To formulate the search strategy for Research Question 1, three conceptual domains were defined: simulation methods, gamification methods, and the construction industry. Within the simulation category, relevant terms included *Simulat**, *Virtual Reality*, *Digital Twin*, and *Monte Carlo simulation*. For gamification, terms such as *Gamif**, *Serious gam**, *Game-based*, and *Stackleberg gam** were used. The construction-related search terms included *Construct**, *Built environment*, *Building industry*, *Build*, and *Construction industry*.

For Research Question 2, additional refinement of the conceptual framework was necessary. Keywords were organised into five thematic categories: (1) lean construction, (2) lean concepts, (3) simulation methods, (4) gamification methods, and the (5) construction industry. Under lean construction, terms such as *lean construction*, *lean principle*, *lean method*, *lean approach*, *lean practice*, *lean management*, and *lean thinking* were used. Lean concepts included *Last Planner System (LPS)*, *Takt Planning*, *5S*, *Target Value Design*, *Just-in-Time*, *Value Stream Mapping*, *BIM*, *Overall Equipment Effectiveness*, *Plan-Do-Check-Act*, and the *Lean Project Delivery System*. Simulation terms mirrored those in RQ1, while gamification terms included *Gamif**, *Serious gam*, and *Game-based gam**. Finally, construction terms were the same as RQ1.

Scopus initially returned no results when all five concepts and associated phrases were combined to address RQ2, likely due to the search's complexity. To improve focus, related concepts were grouped: Lean Construction with Lean Concepts, Simulation Methods with Gamification Methods, and filtered for relevance to the construction industry. Four core concepts from each grouping were used, with terms added iteratively until saturation was reached. Reviewing titles and abstracts of the first ten documents guided adjustments. For instance, the abbreviation "LPS" yielded irrelevant medical results (e.g., "m5C-LPS"), so "Last Planner System" was used instead.

Table 3 presents the search queries for RQ1 and RQ2. The initial RQ1 search retrieved 1,685 documents, later refined by limiting results to (1) a 2014–2024 timeline and (2) engineering relevance. Filtering by Title, Abstract, and Keywords reduced this to 557 documents. Irrelevant studies (e.g., on ADHD, astronauts, or software development) were excluded. A broader search across Abstract OR Keywords fields yielded 395 documents. RQ2 initially produced 459 results, which were refined through keyword and field adjustments. Applying timeline and relevance filters reduced this to 243 documents.

Table 1: Search Terms

Research Question	Input to Scopus Database
RQ1	(simulat* OR "virtual reality" OR "digital twin" OR "monte carlo simulation") AND (gamif* OR "serious gam*" OR "game-based" OR "stackleberg gam*") AND (construct* OR "built environment" OR "building industry" OR build* OR "construction industry")
RQ2	("lean construction" OR "lean principle" OR "lean thinking" OR "Last Planner System" OR "Takt Planning" OR "Just in Time" OR "target value design*") AND (simulat* OR "Virtual Reality" OR "Monte Carlo simulat*" OR gamif* OR "Serious gam*" OR "Stackleberg gam*" OR "digital twin") AND ("Construct*" OR "Built environment" OR "Building industry" OR "Construction industry")

SCREENING METHOD

Excluding source titles from unrelated industries narrowed the findings. To confirm exclusions, publication websites were quickly checked, and industries were categorised as follows: (1) computational science/software engineering, (2) electrical engineering (including IoT and metrology), (3) virtual worlds/metaverse for gaming, (4) education/higher education, (5) medical/science-related, and (6) mechatronics/mechanical engineering (including aviation and energy systems). A second screening process using Rayyan (Ouzzani et al., 2016) ensured accuracy by detecting duplicates and highlighting relevant documents. This was necessary due to Scopus' limitations in duplicate detection. After screening with Rayyan, a strong link between RQ1 and RQ2 was established, as both research questions evaluate simulation and gamification approaches in lean construction in a non-educational setting. Following result consolidation, duplicates were removed, and the final papers were uploaded to NVivo for full-text screening, content analysis, and the development of codes and themes for qualitative analysis.

SOCIAL NETWORK ANALYSIS (SNA)

Social Network Analysis (SNA) was used as a framework to visualise the relationships between lean principles and simulation approaches. Degree centrality was selected as the primary method for network analysis due to its effectiveness in identifying highly connected entities (Elbashbishy et al., 2022). A weighted adjacency matrix was applied, where lean principles are represented as rows and simulation approaches as columns. Cells with direct relationships to lean principles are coloured, while absent relationships are shown as visual gaps.

The adjacency matrix is obtained by multiplying this reference matrix by its transpose.

$$W_{n\times n} = Q_{n\times m} \times Q^{T}_{n\times m}, for\ i \neq j \quad [1]$$

Where: $W_{n\times n}$ = weighted adjacency matrix, $Q_{n\times m}$ = reference matrix, $Q^{T}_{n\times m}$ = reference matrix transposed, n = number of identified principles, m = number of relationships.

The degree centrality of a node (lean principle) measures the total strength of its connections by summing all associated weights from the adjacency matrix.

$$D_i = \sum_{j=1,j\neq i}^{n} W_{i,j} \quad [2]$$

Where: D_i = degree centrality of lean principle i, $W_{i,j}$= weighted relationship between principle i and principle j from the weighted adjacency matrix, $\sum_{j=1,j\neq i}^{n}$ = summation runs across all principles j, excluding self-loops where $i = j$.

Therefore, these equations lay the foundation for a state-of-the-art network analysis. Hence, to quantify these relationships, an analytical matrix was developed: LCPR × SMAP (15×35) which captures the presence and extent of connections between lean principles and simulation approaches.

FINDINGS AND DISCUSSION

Through an extensive content analysis, Table 4, Table 5, and Table 6 present lean principles and simulation approaches identified for their actionable insights and potential beyond purely academic contexts. This review examines various simulation technologies with an emphasis on real-world application. Tools such as BIM are used in design and construction to create virtual replicas that capture a building's physical characteristics and operations (Bhilare et al., 2023). Extended reality technologies, including augmented reality (AR) and virtual reality (VR), enhance user interaction by overlaying digital elements onto the real world or immersing users in fully virtual environments (Bidhendi et al., 2024; Yalçın, 2024). Discrete Event Simulation (DES), introduced to lean construction by Tommelein (1997), models systems as sequences of time-based events. Additionally, digital twin technologies create dynamic virtual counterparts of physical systems to simulate, monitor, and optimise performance (Owais et al., 2024).

CONTENT ANALYSIS

Following the identification and collection of relevant data, a systematic content analysis was conducted to categorise and organise principles and approaches relevant to lean construction, simulation within the construction industry.

Table 2: Relevant Lean Construction Principles

ID	Principles	ID	Principles	ID	Principles
LCPR01	Optimal Scheduling and Planning	LCPR06	Flexibility and Adaptability to Change	LCPR11	Decision-making
LCPR02	Increased Certainty in Project Outcomes and Risks	LCPR07	Focus on Value Delivery for Stakeholders	LCPR12	Enhance Project Management
LCPR03	Visual Management (Kanban Systems)	LCPR08	Improved Communication across multiple Stakeholders	LCPR13	Minimises Defects and Rework
LCPR04	Continuous Improvement (Kaizen)	LCPR09	Increased Productivity	LCPR14	Lower Idle Times
LCPR05	Waste Reduction	LCPR10	Optimal Resource Allocation	LCPR15	Reduced Lead Times

Table 3: Relevant Simulation Approaches

ID	Approaches	ID	Approaches	ID	Approaches
SMAP01	Systemic Process	SMAP13	Influences Decision-making	SMAP25	Safety Planning
SMAP02	Better visualisation of Project Plan	SMAP14	Failure Anticipation	SMAP26	Resource Utilisation Planning
SMAP03	Deliver results	SMAP15	Decision Support Systems	SMAP27	Improved Health and Safety Trainings
SMAP04	Waste Reduction	SMAP16	Improved Construction Quality	SMAP28	Optimisation of Workflows
SMAP05	Time Conservation	SMAP17	Lifecycle Management	SMAP29	Optimal Risk Management
SMAP06	Informed Decision-Making	SMAP18	Customer Satisfaction	SMAP30	Information Management
SMAP07	Accurate Modelling	SMAP19	Immediate Identification for Corrective Actions	SMAP31	Risk and Waste Identification
SMAP08	Sensory Feedback	SMAP20	Versatile	SMAP32	Variation Reduction
SMAP09	Greater Quality Control	SMAP21	Collaborative Visualisation of Information	SMAP33	Minimised Change Orders
SMAP10	Reliable and Transparent Process	SMAP22	Progress Tracking	SMAP34	High cost of technology and software
SMAP11	Reduced Frequency for Site Visits	SMAP23	Visualisation of Discrepancies	SMAP35	Effective communication
SMAP12	Handles Dynamic Changes	SMAP24	Improved Key Performance Indicators		

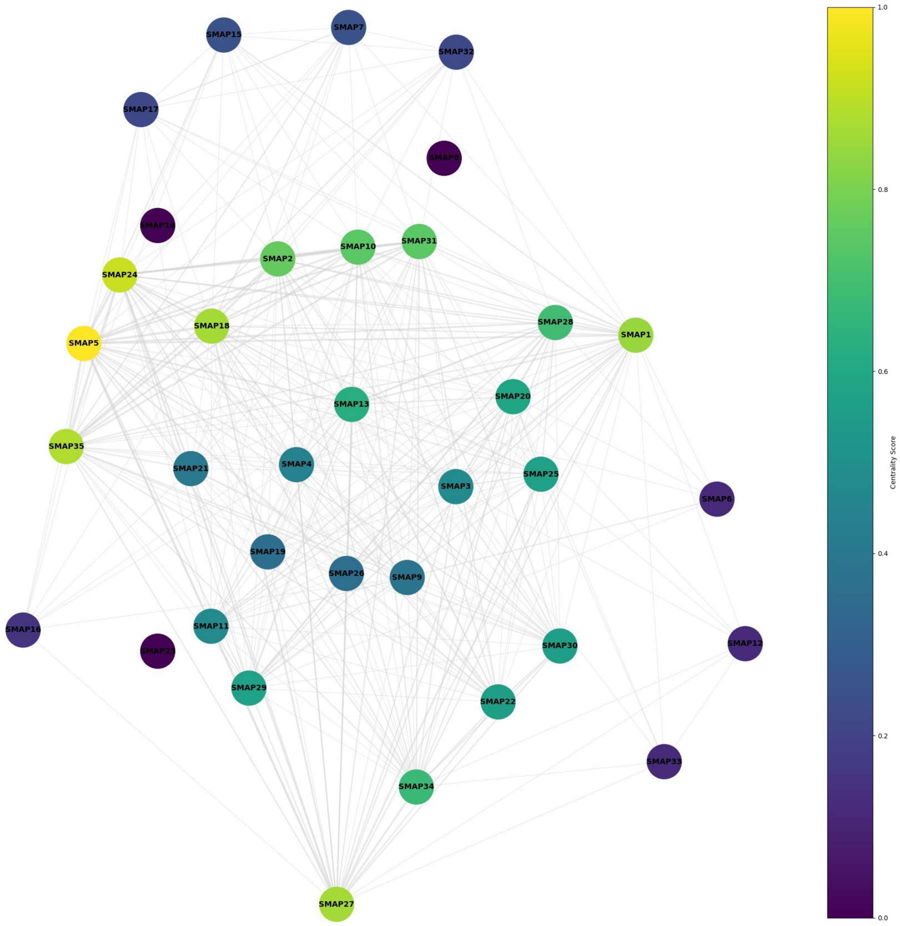

Figure 2: Simulation Approaches Network

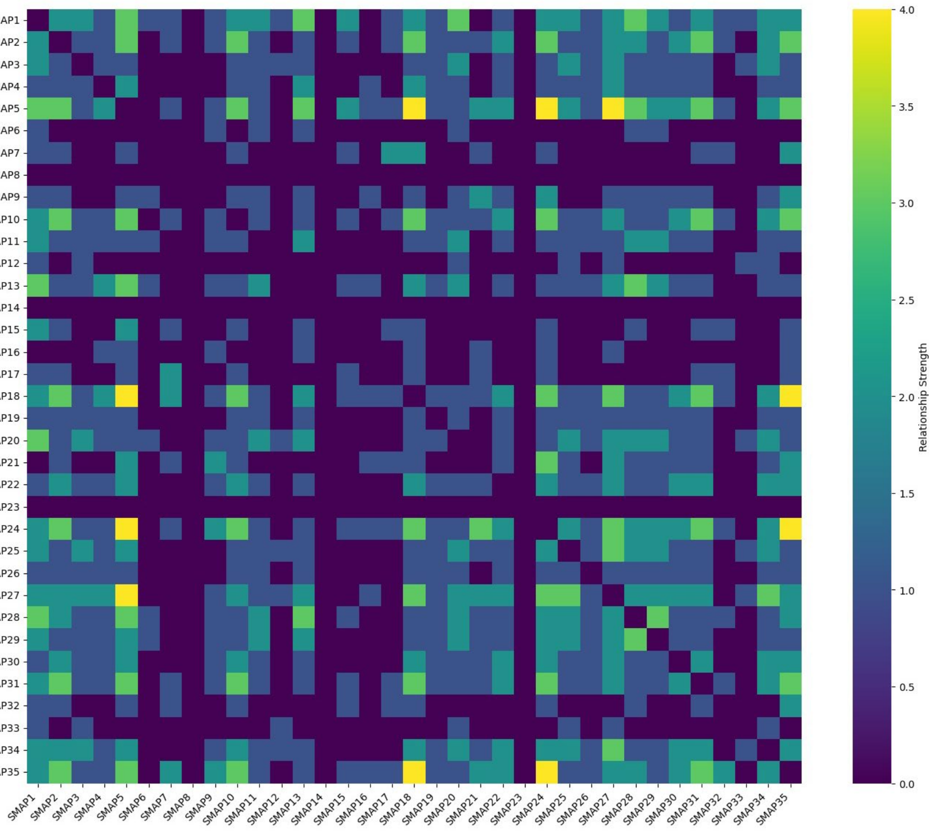

Figure 3: Adjacency matrix of simulation approaches

This study found BIM to be the most reviewed simulation tool, appearing in 25 papers, followed by Extended Realities (AR and VR) in 12 studies, and DES in 9. In contrast, fewer studies focused on Serious Games (6), Monte Carlo Simulation (4), and Digital Twin Technologies (2), suggesting these approaches remain underrepresented in real-world scenarios, with limited evidence of their application in modern construction practices.

The reviewed studies primarily focused on integrating simulation approaches with lean principles such as takt planning, continuous improvement (kaizen), the Last Planner System (LPS), and Just-in-Time (JIT) delivery (Babanagar et al., 2024; Mao et al., 2024). Of the 37 studies analysed, 29 (78%) demonstrated integrated applications of digital technologies with management systems. This prevalence reflects the growing potential of combining advanced technologies with lean principles to reduce waste, improve collaboration, and optimise project delivery. Compared to industries such as manufacturing and logistics — where technologies like digital twins and virtual reality have seen broader adoption (Bidhendi et al., 2024; Owais et al., 2024) the construction sector remains comparatively underdeveloped. Notably, in a Canadian healthcare building project, the integration of 4D-BIM with lean strategies such as takt-time planning resulted in a two-month reduction in the project timeline, exceeding client expectations and strengthening contractors' competitive positioning (Iordanova et al., 2020). As shown in Table 6, stronger connections were identified between lean principles and human-centric simulation approaches (Goh & Chong, 2023), including time conservation, visual-based methods, and transparent, systematic processes that promote usability. In contrast, more complex simulation features such as sensory feedback, real-time failure anticipation, or dynamic system changes which showed limited or no connection to lean principles.

Table 4: Simulation Approaches and their Normalised Degree Centrality

SMAP	C	SMAP	C
SMAP05 (Time Conservation)	1	SMAP03 (Deliver Results)	0.475
SMAP24 (Improved Key Performance Indicators)	0.915	SMAP04 (Waste Reduction)	0.441
SMAP35 (Effective Communication)	0.881	SMAP21 (Collaborative visualisation of information)	0.407
SMAP27 (Improved Health and Safety Trainings)	0.864	SMAP09 (Greater quality control)	0.39
SMAP18 (Customer Satisfaction)	0.864	SMAP19 (Immediate Identification for corrective actions)	0.356
SMAP01 (Systemic Process)	0.847	SMAP26 (Resource utilisation planning)	0.356
SMAP02 (Better visualisation of project plan)	0.763	SMAP07 (Accurate modelling)	0.254
SMAP31 (Risk and waste Identification)	0.746	SMAP15 (Decision support systems)	0.254
SMAP10 (Reliable and transparent process)	0.746	SMAP17 (Lifecycle management)	0.22
SMAP28 Optimisation of workflows)	0.695	SMAP32 (Variation reduction)	0.22
SMAP34 (High cost of technology and software)	0.678	SMAP16 (Improved construction quality)	0.153
SMAP13 (Influences decision-making)	0.627	SMAP12 (Handles dynamic changes)	0.119
SMAP20 (Versatile)	0.593	SMAP33 (Minimised change orders)	0.119
SMAP29 (Optimal risk management)	0.576	SMAP06 (Informed decision-making)	0.119
SMAP25 (Safety Planning)	0.576	SMAP23 (Visualisation of discrepancies)	0
SMAP22 (Progress tracking)	0.559	SMAP14 (Failure anticipation)	0
SMAP30 (Information Management)	0.559	SMAP08 (Sensory Feedback)	0
SMAP11 (Reduced frequency for site visits)	0.475		

CONCLUSIONS AND FURTHER RESEARCH

This study has delivered an in-depth examination of the integration between lean principles in construction and practical simulation approaches through an extensive review of literature and detailed content analysis. The research indicates that the primary focus of non-educational approaches of simulation and gamification approaches should prioritise people over processes. Specifically, the success of these digital tools is less dependent on enhancing their technical complexity or intelligence, and more on their adaptability to the existing skill levels of the workforce. The objectives of these approaches should, therefore, emphasise usability, ensuring that the tools are accessible and relevant to users at various levels of proficiency and financial status. Rather than concentrating on developing increasingly advanced or complex digital methods, it is essential to focus on creating solutions that are intuitive and adaptable, facilitating easier adoption across a diverse range of people. Such an approach would promote smoother integration of digital tools into lean construction practices, ensuring that the digital transformation process is both effective and sustainable, while fostering long-term industry-wide improvements.

The social network analysis highlights strong connections with time conservation with the utilisation of BIM, improved key performance indicators such as with VR, and effective communication such as with implementing DES in key lean principles, particularly in process optimisation, visual management, and workforce training. However, gamification remains underutilised, with limited implementation in non-educational settings and real-time integration despite its potential for improving engagement and performance tracking. Additionally, simulation methods visualisation of discrepancies, failure anticipation, and sensory feedback show no industry adoption, revealing gaps and opportunities in supporting lean construction applications. These findings emphasise the need for further research and strategic implementation to fully leverage digital tools for enhanced efficiency, collaboration, and continuous improvement in construction workflows.

Furthermore, the analysis highlighted key barriers to digitisation of the construction industry. Leading challenges include resistance to change, substantial costs of implementation, and insufficient practitioner training. These obstacles highlight the importance of focused strategies to narrow and potentially overcome the gaps between theoretical promise and real-world application. This study further emphasises that integrating simulation tools and approaches with lean principles, such as takt planning and LPS, can greatly improve project outcomes by minimising waste and fostering collaboration. However, the prevalent adoption of "launch and hope" underscores the structured application of these tools, leading to inefficiencies and significant waste.

It is suggested that future research prioritises empirical studies to validate the practical benefits of these technologies in diverse construction contexts. Thus, allowing for greater analysis of gamification approaches from a non-educational setting. Moreover, extensive industry-academia collaboration can overcome barriers to the digitisation of the construction industry. Through, a collective focus on developing accessible frameworks and user-centric training programs. Therefore, leveraging the full potential of digital tools to drive innovation, enhance efficiency, and achieve sustainable project outcomes.

REFERENCES

Abbasi, S., Taghizade, K., & Noorzai, E. (2020). Bim-based combination of takt time and discrete event simulation for implementing just in time in construction scheduling under constraints. *Journal of Construction Engineering and Management*, *146*(12). https://doi.org/https://doi.org/10.1061/(ASCE)CO.1943-7862.0001940

Akindele, N., Taiwo, R., Sarvari, H., Oluleye, B. I., Awodele, I. A., & Olaniran, T. O. (2024). A state-of-the-art analysis of virtual reality applications in construction health and safety. *Results in Engineering*, *23*. https://doi.org/doi:10.1016/j.rineng.2024.102382

Aliu, J., Oke, A. E., Abayomi, T., Aigbavboa, C., & Makanjuola, S. (2023). Exploring the critical success factors for adopting gamification in the Nigerian construction sector. *Built Environment Project and Asset Management*, *14*(2), 184-200. https://doi.org/10.1108/bepam-08-2023-0150

Alves, S., Melzner, J., & Hollermann, S. (2022). Lean simulation game with BIM-Based progress monitoring for takt control. *Proc. 30th Annual Conference of the International Group for Lean Construction (IGLC)*, *30*, 307-317. https://doi.org/https://doi.org/10.24928/2022/0132

Arefazar, Y., & Rybkowski, Z. (2022). Developing & Testing a Value Stream Map Simulation: Helping the Construction Industry Learn to See. *Proc. 30th Annual Conference of the International Group for Lean Construction (IGLC)*. https://doi.org/https://doi.org/10.24928/2022/0135

Babanagar, N., Sridharan Srinivasan, N., & Rakshith, N. (2024). *Case Study on Production System Design with Discrete Event Simulation for Bangalore Metro Underground Project* (Vol. 383). https://doi.org/doi:10.1007/978-981-99-5455-1_19

Bhilare, S., Khatri, D., Rangnekar, S., & Chen, Q. (2023). *Using BIM to Facilitate Generative Target Value Design for Energy Efficient Buildings*. https://doi.org/doi:10.22260/ISARC2023/0093

Bidhendi, A., Poshdar, M., Nahri, Z., Won, J. W., Owais, O. A., Koohestani, K., Costa, B., Drevland, F., & Florez-Perez, L. (2024). Enhancing lean construction through innovative technology: a focus on virtual reality in construction. *Proceedings of the 32nd Annual Conference of the Internation Group for Lean Construction (IGLC)*, 743-754. https://doi.org/https://doi.org/10.24928/2024/0187

Clavel, I. M., Florez-Perez, L., & Zarco, C. G. (2024). Real-Time Strategy in Construction Scheduling: a game-based interactive framework integrating BIM, Unreal Engine, and simulation. 274-283. https://doi.org/http://dx.doi.org/10.2139/ssrn.5129656

Dobrucali, E., Demirkesen, S., Sadikoglu, E., Zhang, C., & Damci, A. (2024). Investigating the impact of emerging technologies on construction safety performance. *Engineering, Construction and Architectural Management*, *31*(3), 1322-1347. https://doi.org/doi:10.1108/ECAM-07-2022-0668

Elbashbishy, T. S., Ali, G. G., & El-adaway, I. H. (2022). Blockchain technology in the construction industry: mapping current research trends using social network analysis and clustering. *Construction management and economics*, *40*(5), 406-427. https://doi.org/https://doi.org/10.1080/01446193.2022.2056216

Farouk, A. M., & Rahman, R. A. (2023). Integrated applications of building information modeling in project cost management: a systematic review. *Journal of Engineering, Design and Technology*. https://doi.org/doi:10.1108/JEDT-10-2022-0538

Forcael, E., Contreras, C., Francesconi, C., & Baesler, F. (2024). Applying Game Theory to Teach the PERT Scheduling Method. *Applied Sciences*, *14*(24), 12045. https://doi.org/https://doi.org/10.3390/app142412045

Goh, C. S., & Chong, H.-Y. (2023). Opportunities in the sustainable built environment: perspectives on human-centric approaches. *Energies*, *16*(3), 1301. https://doi.org/https://doi.org/10.3390/en16031301

Ilbeigi, M., Bairaktarova, D., & Morteza, A. (2023). Gamification in construction engineering education: A scoping review. *Journal of Civil Engineering Education*, *149*(2), 04022012. https://doi.org/https://doi.org/10.1061/(ASCE)EI.2643-9115.0000077

Iordanova, I., Valdivieso, F., Filion, C., & Forgues, D. (2020). *Schedule optimization of a large hospital project – 4D BIM starting with the demolition*. https://doi.org/doi:10.24928/2020/0048

Jacobsen, E. L., Strange, N. S., & Teizer, J. (2021). Lean construction in a serious game using a multiplayer virtual reality environment. *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC)*, 55-64. https://doi.org/doi.org/10.24928/2021/0160

Kalvik, S. (2024). *Automation in Systematic Literature Searching: Assessing current methods and future development* Oslo Metropolitan University].

Liu, C., González, V. A., Liu, J., Rybkowski, Z., Schöttle, A., Álvarez, C. M., & Pavez, I. (2020). Accelerating the last planner system® (LPS) uptake using virtual reality and serious games: A sociotechnical conceptual framework. *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC)*, 481-492. https://doi.org/doi:10.24928/2020/0058

Mao, W., Ran, K., Wang, T.-K., Yu, A., Lv, H., & Chen, J.-H. (2024). An optimization model for just-in-time (JIT) delivery of precast components considering 3D loading constraints, real-time road conditions and assembly time. *Engineering, Construction and Architectural Management*. https://doi.org/doi:10.1108/ECAM-04-2023-0372

Oke, A. E., Aliu, J., Tunji-Olayeni, P., & Abayomi, T. (2024). Application of gamification for sustainable construction: an evaluation of the challenges. *Construction Innovation*, *24*(4), 1066-1084. https://doi.org/https://doi.org/10.1108/CI-09-2022-0247

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan—a web and mobile app for systematic reviews. *Systematic reviews*, *5*, 1-10. https://doi.org/https://doi.org/10.1186/s13643-016-0384-4

Owais, O. A., Poshdar, M., Bidhendi, A., Jaafar, K., & Sarhan, S. (2024). From Concept to Concrete: Digital Twins Enabling Different Levels of Lean Construction. *Proc. 32nd Annual Conference of the International Group for Lean Construction (IGLC)*, 767-779. https://doi.org/doi.org/10.24928/2024/0206

Piras, G., Muzi, F., & Tiburcio, V. A. (2024). Digital Management Methodology for Building Production Optimization through Digital Twin and Artificial Intelligence Integration. *Buildings*, *14*(7). https://doi.org/doi:10.3390/buildings14072110

Pütz, C., Lühr, G., Wenzel, M., & Helmus, M. (2021). Potential of gamification for lean construction training: An exploratory study. *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC)*, 258-268. https:// 10.24928/2021/0134

Shannon, R. E. (1992). Introduction to simulation. *Proc. 24th conference on Winter simulation*, 65-73. https://doi.org/https://doi.org/10.1145/167293.167302

Sharma, D., & Sharma, J. (2023). Evolution of gamification, its applications, and its statistical impact on the society. *International Conference on Emerging Trends in Design & Arts*, *4*(2SE), 8-20. https://doi.org/10.29121/shodhkosh.v4.i2SE.2023.456

Shehab, L., Ezzeddine, A., Hamzeh, F., & Power, W. (2020). *Agent-based modelling and simulation of construction crew performance*. https://doi.org/doi:10.24928/2020/0012

Stevens, M., & Poshdar, M. (2024). Lean Construction Enterprise Management: The Value and Potential of the Merit Game Simulation. *Proc. 32nd Annual Conference of the International Group for Lean Construction (IGLC)*, 1293-1302. https://doi.org/10.24928/2024/0102

Tommelein, I. D. (1997). Discrete-event simulation of lean construction processes. *Proc. 5th Conference of the International Group for Lean Construction*, 121-136.

Yalçın, Z. Ö. (2024). Integrating Gamification with BIM for Enhancing Participatory Design. *Journal of Computational Design*, *5*(2), 317-344. https://doi.org/10.53710/jcode.1505309