Gamification in Construction Engineering Education: A Scoping Review

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Abstract: The long history of experiential learning in construction engineering shows the significant potential of cognitive development through direct experience. Recent advancements in gamification, especially digital serious games, can help educators develop novel pedagogical strategies to promote active and experiential learning in controlled settings. Despite considerable attention to this field during the last two decades, game-based educational solutions for construction engineering are far from achieving their full potential, and still little is known about systematic ways to direct research and development works in this domain. The first step toward developing systematic plans to advance research in this area is to analytically understand the extent, range, and nature of the existing research to identify research gaps and potential directions for future studies. This study addresses this need through a scoping review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Review (PRISMA-ScR). Throughout the research process, we identified 103 relevant studies. We extracted two sets of information from each document during the review process. The first set incorporates basic attributes of the publications, including the type of the document, publication year, and author affiliation. The second set of information concentrates on the contents of the documents to analyze their contextual characteristics and contributions to the field. Using the extracted information, we discuss the limitations in the state-of-the-art research in this rapidly growing field and propose a set of potential directions and considerations for future studies. **DOI: 10.1061/(ASCE)EI.2643-9115.0000077.**

Author keywords: Gamification; Construction engineering education; Scoping review; Preferred reporting items for systematic reviews and meta-analysis extension (PRISMA).

Introduction

The US construction industry has more than 680,000 employers with over 7 million employees and creates nearly $1.3 trillion worth of structures each year (Brown 2019). However, this critical industry is overwhelmed by delays and suffers from inefficiency and cost overruns (Assaf and Al-Hejji 2006; Zidane and Andersen 2018). In addition, unprecedented challenges, including climate change, population growth, and rapid technological revolutions, make construction projects even more complicated. Construction engineering, at the nexus of engineering design and project execution processes, aims to apply technical and scientific knowledge to plan, execute, and manage construction projects successfully. However, the existing construction engineering programs need transformational changes to successfully prepare the next generations of construction engineers with a deep understanding of fundamental concepts and a repertoire of practical skills, so they can find innovative solutions to new challenges.

Previous studies convincingly showed that active and collaborative instruction, coupled with effective means to encourage student engagement, invariably leads to better student learning outcomes irrespective of academic discipline (Weimer 2002). In addition, the long history of experiential learning in construction engineering shows the significant potential of cognitive development through direct experience and reflection on what works in particular situations (Kuh et al. 2011). Of course, the complex nature of the construction industry in the 21st century cannot afford an education through trial and error in real environments (Le et al. 2015). However, recent advances in gamification, especially digital games, can help educators develop game-based pedagogical strategies. These novel strategies allow students to explore various scenarios and learn from their experiences in controlled settings (Huang and Soman 2013).

Designing and implementing effective game-based pedagogical strategies is a complex and multidisciplinary endeavor that may be financially expensive and time-consuming. Despite the considerable investments in designing and developing gamified educational strategies in the last two decades, little is known about systematic approaches to direct future research and development efforts in this field for the construction sector. The overarching objective of this study is to fill this gap in knowledge by conducting a scoping review to systematically analyze and map the research done in this domain to identify potential directions for future studies. Particularly, this study addresses two questions: (1) What is known from the literature about gamified solutions for education and training in the construction industry? (2) What are the potential future research directions and considerations in gamification for education and training in the construction industry?

In this study, we address these questions using a scoping review. A scoping review is a relatively new approach to evidence synthesis through a comprehensive and structured literature search (Levac et al. 2010). Despite a systematic literature review focusing on well-defined questions about a specific topic, a scoping review tends to address broader questions (Arksey and O'Malley 2005). Particularly, scoping reviews are applicable for examining the

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extent (i.e., size), range (i.e., variety), and nature (i.e., characteristics) of research activities in a field and identifying the research gaps in the existing literature (Munn et al. 2018). This type of synthesis study analyzes the overall scope of the studies and typically does not evaluate their quality (Rumrill et al. 2010). Scoping reviews can contribute in particular to disciplines with emerging evidence to map existing knowledge and justify future research directions (Torres-Carrión et al. 2018).

Throughout the scoping review, we identify relevant studies using a series of inclusion criteria based on related keywords. Next, we collect two sets of information from each document. The elements in these sets were selected based on the objectives of the study and also previous works on analyzing gamification in educational settings, including Swacha (2021), Palomino et al. (2019), and Rabah et al. (2018). The first set incorporates the basic attributes of the publications, including the type of the document (e.g., peer-reviewed journal paper, conference proceedings, and book chapter), publishers, authors' affiliation, and publication year.

The second set of information concentrates on the contents of the documents that offered a gamified solution for construction engineering education. To extract this type of information from the identified relevant studies and analyze their contextual characteristics and contributions to this field of research, we defined the following six questions and assessed how the studies addressed them:

1. Did the research use a commercially available game or create a new serious game for education or training in the construction domain?
2. Was the proposed serious game digital or physical?
3. What specific aspects of the construction process (e.g., safety, sustainability, economic decision-making) were targeted in the proposed gamified solutions?
4. If the primary purpose of the game was not education or training, what was it?
5. Did the research empirically assess the performance of the proposed gamified solution? If yes, how?
6. Did the research base the proposed gamified solution on a theoretical learning framework?

In the remainder of this paper, after a brief introduction to the technical definition of games and gamification, we introduce our search and synthesis method. We then explain the steps conducted during the search process. Next, we report and discuss the findings. Finally, we summarize the outcomes and limitations of this study in the concluding section.

Games and Gamification

Bernard Suits (2014), a Canadian philosopher, defined a game as "the voluntary attempt to overcome unnecessary obstacles" that has three components: prelusory goal, constitutive rules, and lusory attitude.

Gamification or serious games apply game elements and principles in nongame contexts (Dicheva et al. 2015). Appropriately designed, serious games can provide an interactive environment where users can engage with technical contexts, explore different scenarios, acquire new knowledge, and connect that knowledge to their existing mental models (Deshpande and Huang 2011). The term gamification was coined by Nick Pelling in 2002 and hit the mainstream around 2010 (Pelling 2011). The elements of a gamified system can be categorized into three groups: (1) dynamics: which defines the big picture aspect of the game and includes elements such as constraints, narratives, progression, and relationships; (2) mechanics: which defines the processes that drive actions forward and includes elements such as challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns, and win states; and (3) components: which shows specific instantiations of mechanics and dynamics and includes elements such as points, quests, achievements, badges, avatars, and virtual goods (Werbach and Hunter 2012).

Search and Synthesis Method

In this study, we conduct a scoping review using a search protocol based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Review (PRISMA-ScR) developed by Tricco et al. (2018).

Our search and synthesis process consists of the following six main steps (Fig. 1):

1. Defining the eligibility criteria that determine the inclusion or exclusion of a document in the final synthesis.
2. Determining the information source where the search will be conducted.
3. Designing the search strategy, including the search queries.
4. Conducting the search and identifying the relevant documents by reviewing the title, abstract, and keywords of the documents listed as the outcomes of the queries.
5. Reviewing the full manuscripts of the identified relevant publications for data extraction and charting.
6. Synthesizing the extracted information to understand the extent of the existing research, identify the knowledge gaps, and determine the potential future research directions in this area.

In the remainder of this section, we briefly explain each step.

Step 1: Defining the eligibility criteria

Any technical document, including peer-reviewed journal papers, conference proceedings, and book chapters, that discusses the application of gamification in construction engineering education and training is included in the review if it is written in English. Considering the recency of the topic, we did not limit the search process based on the publication date.

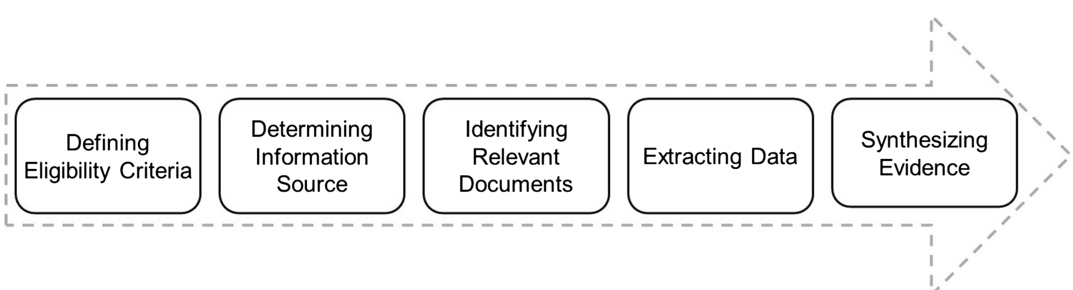

Fig. 1. Search and synthesize process.

Step 2: Determining the information source

To identify potentially relevant documents during the scoping review, we searched the Scopus bibliographic database. This database, created by Elsevier, indexes a wide range of subjects from a long list of publishers, including the leading journals and conferences related to the Architecture, Engineering, and Construction (AEC) sector. Gusenbauer and Haddaway (2020) investigated the capabilities and performance of many bibliographic databases using a wide range of factors, including their query options, Boolean operators, and data set structures. The outcomes of their investigation identified Scopus as one of the reliable sources for systematic review.

Step 3: Designing the search strategy

Our search strategy was based on the existence of various combinations of phrases related to gamification and the construction industry in the title, abstract, or keywords of a publication. In particular, we used the following search query to list the potentially relevant studies:

("gamification" OR "gamified" OR "serious game") AND ("construction" OR "civil eng" OR "AEC")*

The first part of the search query included phrases related to gamification. The second part consisted of phrases linked to the construction industry.

Step 4: Identifying the relevant documents

The search query, conducted on November 21, 2021, resulted in a list of 518 documents. By reviewing the abstracts of the listed publications, we identified 112 studies that meet our inclusion criteria and could be considered relevant to the topic.

Step 5: Reviewing the full manuscripts

In Step 5, we reviewed the full manuscripts of the 112 relevant documents to extract the information mentioned in the introduction that helped us address the research questions and objective of this study. During the review process, we observed that some journal articles were extended versions of some conference papers. For example, Castronovo et al. (2017a) is a conference paper presented at the *2017 International Conference on Computing in Civil Engineering*. This publication introduced a game-based teaching strategy using a virtual construction simulator and collected data from 34 students to examine their level of enjoyment when using the game. Castronovo et al. (2017b) is an extended version of that research published in the *International Journal of Engineering Education*. This study assessed the proposed gamified solution more rigorously using the data collected from the 34 students to understand the solution's impact on students' problem-solving skills. To avoid duplications from these cases in the synthesized outcomes of the scoping review, we removed the preliminary versions (mostly conference papers) from the list of the relevant documents and kept the more comprehensive versions (mostly journal articles). This reduced the total number of identified relevant studies to 103. The outputs of this step are a series of data collected for each reviewed study.

Step 6: Synthesizing the extracted information

In this step, we synthesize the extracted data from the documents to map and analyze the scope and contributions of the existing research in this area and identify the limitations, gaps in knowledge, and potential future directions for research and scholarly works.

Synthesizing the extracted information is aligned with the two sets of data collected from the studies. The process begins by summarizing the basic attributes of the shortlisted publications. Fig. 2 shows the distribution of the 103 identified relevant publications based on their publication year. The oldest study was published in 2007. The evident upward trend in the number of publications in recent years shows the increasing attention that the research community is paying to this rapidly developing topic.

In terms of publication types, the identified 103 relevant documents consist of 41 peer-reviewed journal publications, 60 conference proceedings, and 2 book chapters (Fig. 3). These documents were published in 76 different sources, including 33 journals and 41 conferences. The *Journal of Construction Engineering and Management*, published by ASCE, has the highest number of publications among the journal publications, with four articles. With five publications, the *ASCE International Conference on Computing in Civil Engineering* has the greatest number of documents among the conference proceedings.

The relevant documents can be categorized into three groups based on their contents and scopes: (1) studies that proposed a gamified solution to education or training, (2) studies that offered gamified solutions for noneducational purposes, and (3) studies that contributed to this field but did not develop a specific gamified solution. Fig. 4 shows these categories. The number of studies in each category and its subcategories is shown in parentheses. In the remainder of this section, these three categories are discussed.

Results

Studies That Proposed a Gamified Solution to Education or Training

Reviewing the contents of the 103 relevant documents revealed that 57 publications (23 journal articles and 34 conference papers) proposed a specific gamified solution. The primary topic of most of these proposed gamified solutions (i.e., 49 out of the 57) was education and training. These studies included 18 journal articles and 31 conference papers. Among the 49 proposed educational gamified solutions, 31 were digital, 13 were physical (i.e., board games or role playing), and 5 were hybrid (i.e., a combination of physical and digital components). Forty studies created a new game, and the other nine studies used existing games, including commercial ones (e.g., Kahoot), for their proposed gamified pedagogical strategies.

These proposed gamified solutions for education and training targeted various aspects of construction engineering. Fig. 5 summarizes the number of studies in each area. With 13 proposed gamified solutions, occupational safety has received the greatest level of attention, followed by sustainability, lean construction, and construction methods (6 publications for each).

Of the 49 studies that proposed an educational gamified solution empirically, 40 assessed their proposed solution to examine their performance from different perspectives. Most of the assessments were based on surveys, semistructured interviews, and pre- and post-assessment tests. Twelve studies went one step further and analyzed game data (e.g., log files created in digital games based on the actions taken by players) to evaluate students' learning through the proposed gamified solution. Using game data to assess and monitor students' learning can provide a reliable source of information to effectively monitor learners' progress and guide them throughout the game.

Another aspect of analyzing the identified educational gamified solutions is whether they are based on a theoretical learning framework. Learning theories aim to objectively understand how people learn and systematically design pedagogical strategies and teaching methods (Schunk 2012). Some learning theories, including behaviorism (Skinner 1976), cognitivism (McLeod 2003), constructivism (Fosnot 2013), humanism (Huitt 2009), and connectivism

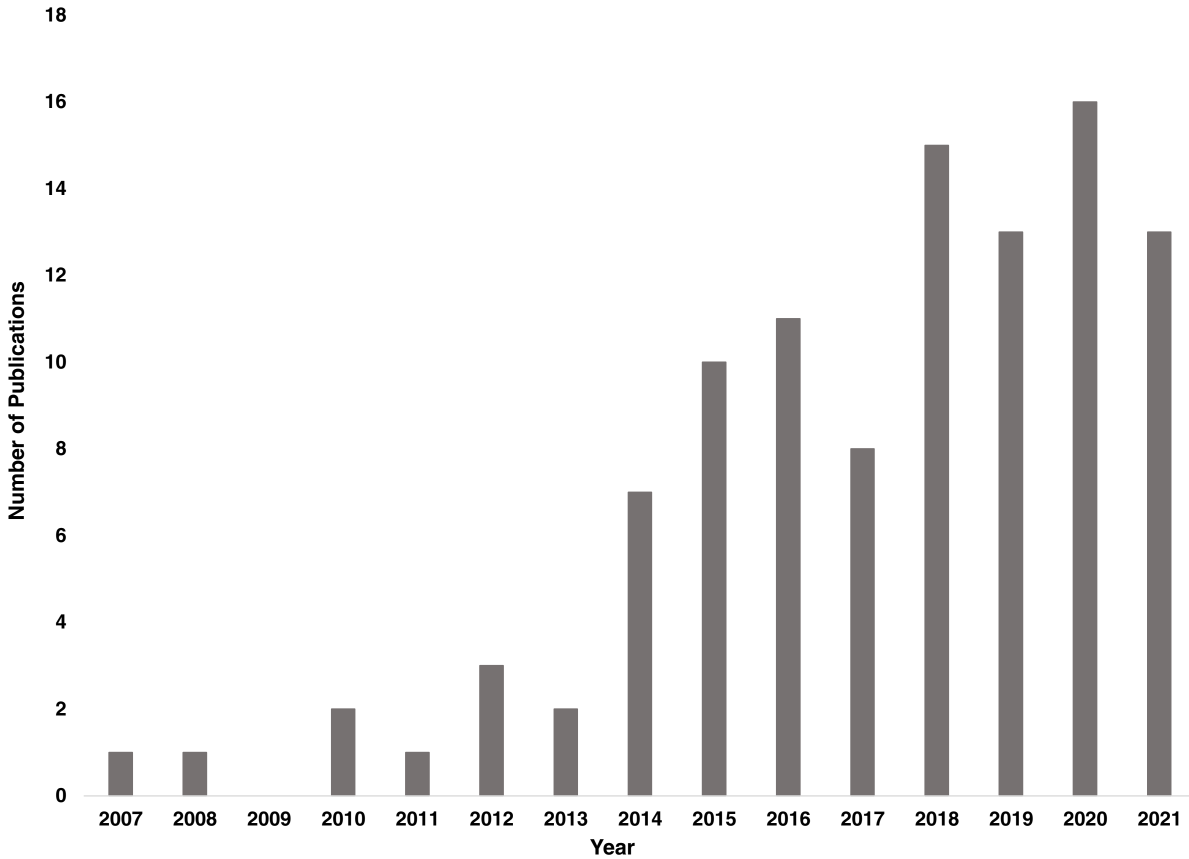

Fig. 2. Distribution of relevant publications based on their publication year.

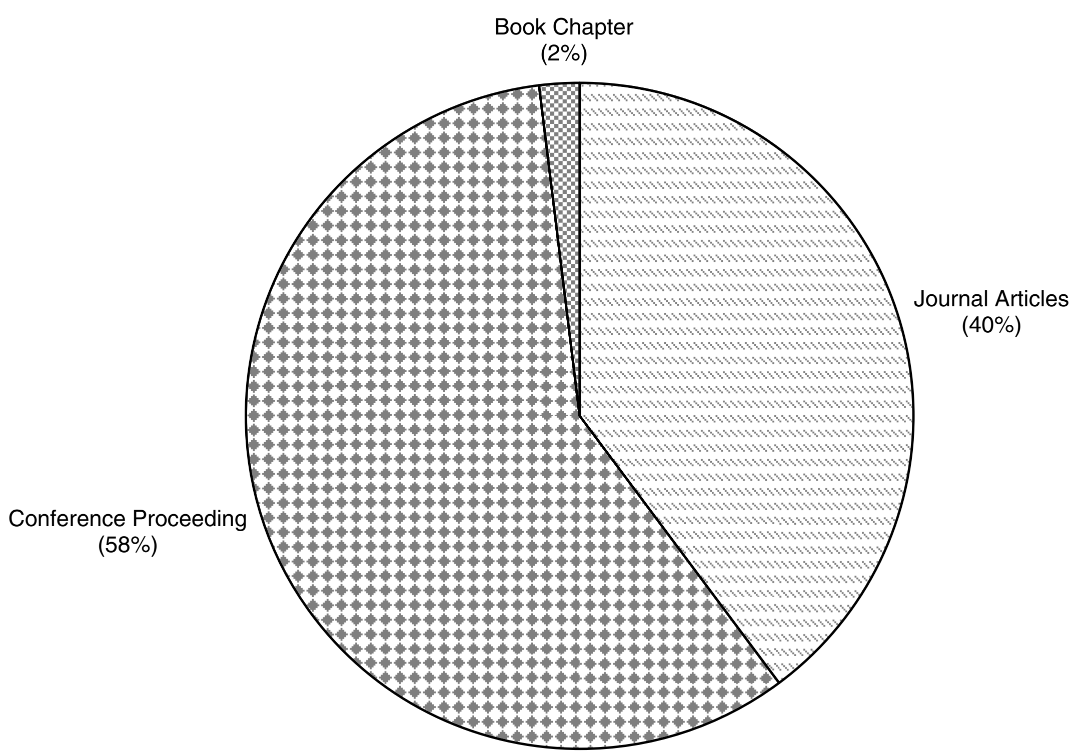

Fig. 3. Percentage of publication types in relevant documents.

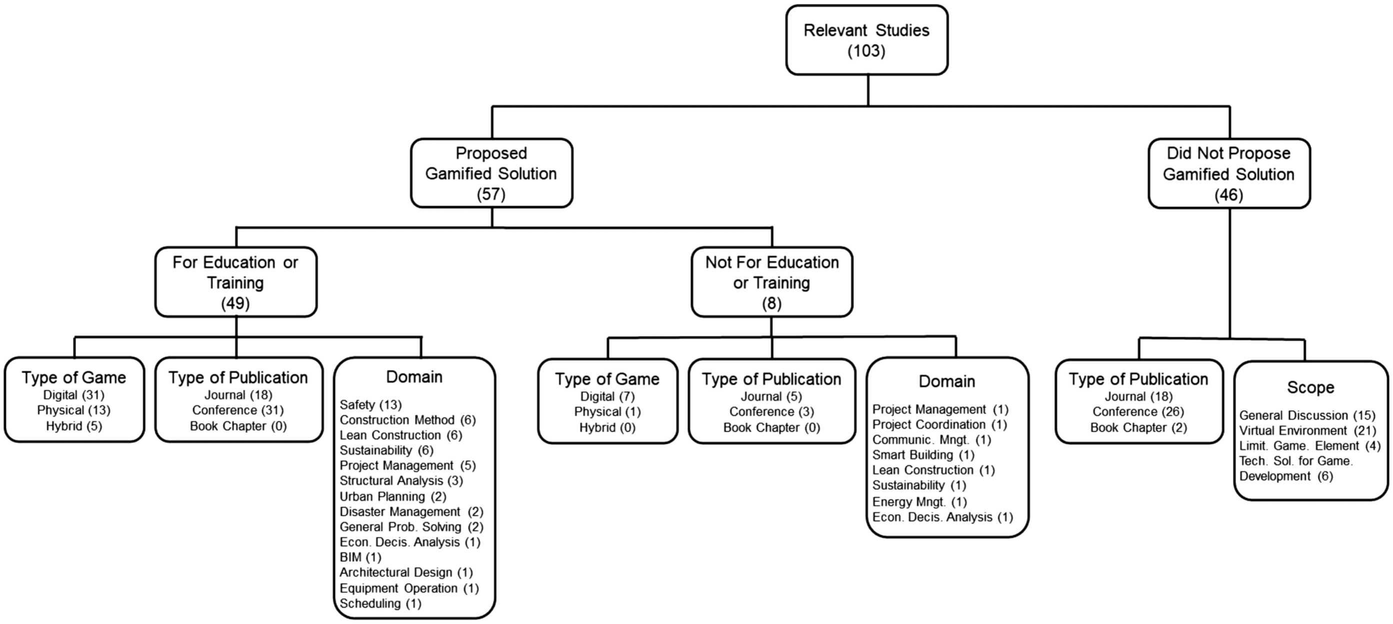

Fig. 4. Distribution of relevant studies across primary categories.

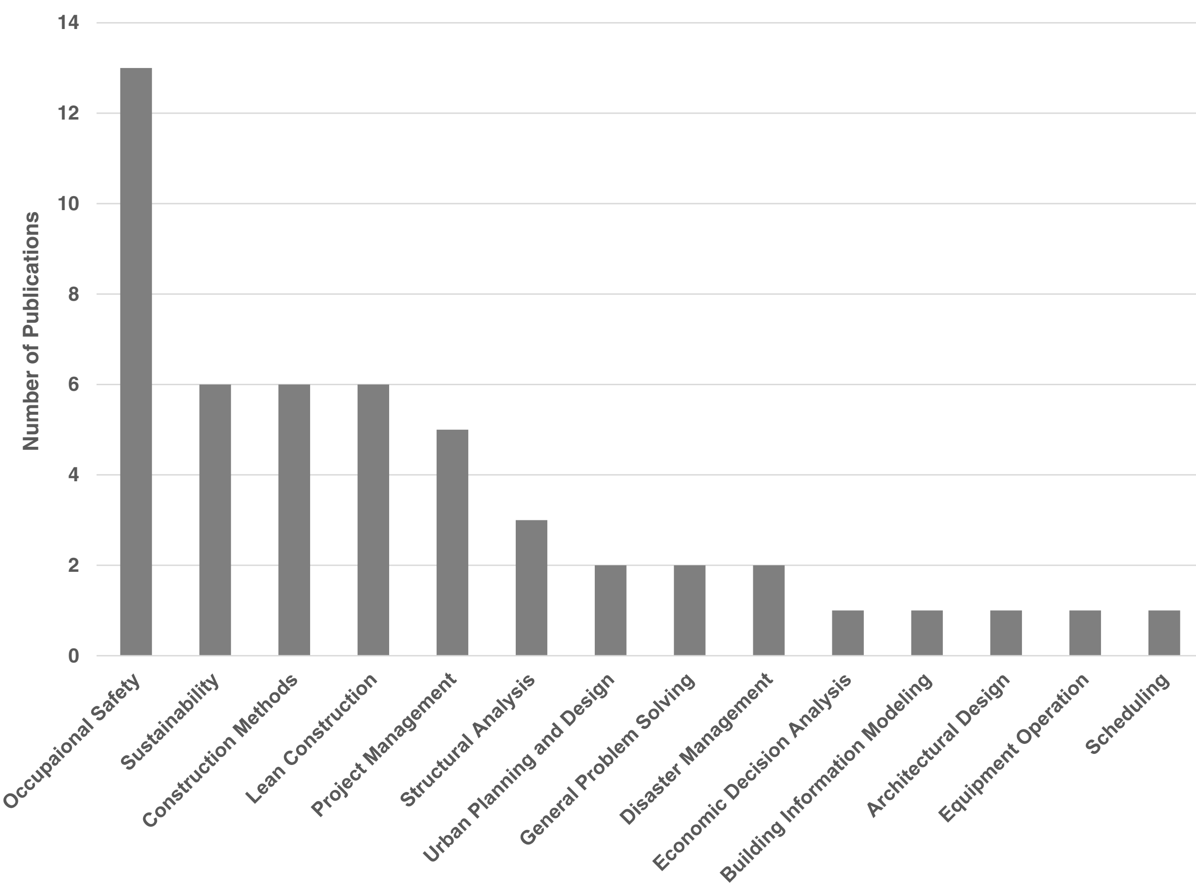

Fig. 5. Number of studies in each educational topic.

(Goldie 2016), have received more attention in cutting-edge research and scholarly works (Fairbanks 2021).

In addition, other theories and frameworks can play a significant role in developing novel pedagogical strategies. For example, adult learning theories, rooted in andragogy, that differentiate the learning process in adults from cognitive development in children (Bélanger 2011) can help educators design effective vocational training and reskilling programs.

Despite the criticality of learning theories for systematically designing pedagogical strategies, only 5 out of the 49 studies that proposed a gamified solution for education or training considered a learning theory. Two of these studies, Dickinson et al. (2011) and Castronovo et al. (2017b), only mentioned constructivism learning theory very briefly without establishing their developed game-based educational methods on a detailed framework or explaining how their game components are designed according to the framework.

The other three studies took learning theories more seriously and designed their proposed gamified solutions accordingly. Lee et al. (2020) developed a simulation game-based assignment for construction safety designed based on authentic learning. Authentic learning is an instructional approach based on situated learning models that promote learning in a setting relevant to the real-world situation in which the learners will apply their knowledge (Lombardi and Oblinger 2007). Situated learning stems from constructivist learning theory (Anderson et al. 1996). In addition to designing the game-based assignment, their study assessed the nine characteristics of an authentic learning environment defined by Herrington and Kervin (2007) in their proposed gamified solution.

George et al. (2016) proposed a gamified simulation to train crane operators. When developing the gamified training, they considered the nine instructional events in Gagne's condition of learning theory (Gagné 1985). The nine events are as follows: (1) gaining attention, (2) informing learners of the objective, (3) stimulating recall of prior learning, (4) presenting the stimulus, (5) providing learning guidance, (6) eliciting performance, (7) providing feedback, (8) assessing performance, and (9) enhancing retention and transfer.

Hartmann (2016) argued that activity theory (Vygotsky 1978) could adequately explain the effects of serious games on the learning behavior of students in the context of construction management, and sensemaking theory (Weick 1995) could be used to explain learners' behavior during educational experiments using serious games. He then developed a board game that simulates the long-term design, construction, and facility management activities related to a hospital and used it to conduct experiments to support the proposed arguments. Table 1 summarizes some aspects of the collected data for this group of studies.

Noneducational Gamification Solutions

Although the focus of this study is on gamification for construction engineering education, the limited number of studies that offered gamified solutions for noneducational goals may still have the potential to contribute to the domains directly or indirectly linked to education and training. Therefore, we briefly review them in this section. The eight publications that proposed a gamified solution but not for an educational or training purpose consist of five journal articles and three conference proceedings. All proposed gamified solutions were digital. Seven studies developed new games, and one used a commercially available game. Neto et al. (2014) used digital gamified solutions to encourage construction workers to follow weekly plans and schedules through healthy competitions. Wu and Kaushik (2015) integrated gamification elements into building information modeling (BIM) models to improve communications during the design phase of construction projects. Fogli et al. (2016) developed a prototype mobile application using gamification elements (e.g., rewards and rules) to engage family members in the management of their smart homes. Jeffrey (2016) introduced a gamified system using BIM, titled Playconstruct, to facilitate decision-making throughout the planning of a construction project by fostering engagement and collaboration among project stakeholders. Leite et al. (2016) designed and implemented a web-based tool called Gamified Construction Project System to improve communication and transparency in managing construction projects. Nichols (2018) developed a web-based game for economic analysis in reverse auction biddings in the construction sector. Poplin (2020) created an online energy game called e-footprint that collects data about building occupants' energy consumption behavior. Zhang et al. (2021) used a commercially available game, Nova Empire, to simulate and analyze various social factors linked to sustainable societies.

Studies That did not Propose a Specific Gamified Solution

The 46 studies that did not propose an explicit gamified solution can be categorized into four groups. The first group consisted of 15 publications (including 7 journal articles, 7 conference papers, and 1 book chapter) that provided very general and high-level discussions about the importance of gamification in construction engineering. These studies neither proposed a gamified solution nor contributed to extending the body of knowledge in this field from a technical perspective. The second group of studies, which contained 21 publications (including 7 journal articles and 14 conference papers), focused on creating virtual environments using three-dimensional (3D) simulations and immersive virtual reality (VR) rather than designing and developing an interactive game. Although these studies clearly labeled their works using phrases related to gamification, serious games, and gamified solutions, their final products cannot be considered a game based on the scientific definition of a game introduced by Bernard Suits (2014) that was reviewed in the introduction of this paper. In addition, the final products of these studies do not contain critical gamification elements, such as constraints, competition, cooperation, reward, and feedback.

The third group of studies, which included four publications (including three journal articles and one conference paper), used certain limited elements of gamification, such as points or visualization, to create more attractive platforms for different purposes, such as education. Although these studies used some elements of gamification, they did not create an interactive game environment in which users could explore different strategies to achieve a goal. For example, Gonzalez (2018) developed a feedback-rich digital environment where students answer civil engineering questions and get immediate feedback about their responses. In another study, Reyes et al. (2021) proposed a contest in a construction building and materials course to engage better and motivate students. Finally, de Ruyck et al. (2020) proposed a digital dashboard to provide visual feedback about energy consumption to residents of a building.

The fourth group of studies, which included six publications (including one journal article, four conference papers, and one book chapter), offered some technical solutions for creating serious games for the construction domain. For example, Lee et al. (2014) analyzed the 3D simulation parameters of a construction site (e.g., texture and lighting) for serious games related to safety in order to align them with game contents and better influence and engage users. Schatz and Rüppel (2015) proposed an ontology-based method to create game objects in AEC projects using BIM files. Freire et al. (2015) conducted a Delphi study to identify the requirements of a serious game for masonry structural analysis. They categorized the requirements into five groups: functional, data, environment, user, and usability. Table 2 shows the studies in each group.

Discussion: Limitations, Potentials, and Future Directions

The synthesized data extracted from the identified relevant publications help us understand the limitations of the state-of-the-art

Table 1. Studies that proposed a gamified solution for education or training

Study	Type	Domain	Type of game	Empirical assessment?	Game data evaluation?	Learning theory?
Clark et al. (2021)	J	Sustainability, construction methods	Physical	Y	N	N
Patil and Kumbhar (2021)	J	Structural analysis	Digital	Y	N	N
Kazar and Comu (2021)	J	Occupational safety	Digital	Y	N	N
Rogora (2021)	J	Sustainability	Physical	N	N	N
Tagliabue et al. (2021)	J	Lean construction	Hybrid	Y	Y	N
Lee et al. (2020)	J	Occupational safety	Hybrid	Y	N	Y
Carlson and Wong (2020)	C	Sustainability	Physical	Y	N	N
Josiek et al. (2020)	C	Econnomic decision analysis	Digital	Y	Y	N
Sousa (2020)	C	Urban plannig and design	Physical	Y	N	N
Pütz et al. (2020)	C	BIM	Physical	Y	N	N
ElGewely and Nadim (2020)	C	Construction methods	Digital	N	N	N
Pietrafesa et al. (2020)	C	Occupational safety	Digital	Y	N	N
Liu et al. (2020)	C	Lean construction	Digital	N	N	N
Kamkuimo et al. (2020)	C	Occupational safety	Digital	Y	N	N
Teizer et al. (2020)	C	Lean construction	Digital	Y	Y	N
Bükrü et al. (2020)	C	Occupational safety	Digital	Y	Y	N
Khanzadi et al. (2019)	J	Lean construction	Digital	Y	N	N
Din and Gibson (2019)	J	Occupational safety	Digital	Y	Y	N
Khah et al. (2019)	C	Architectural design	Physical	Y	N	N
Musa et al. (2019)	C	Lean construction	Physical	Y	N	N
Iori et al. (2019)	C	Construction methods	Physical	N	N	N
Golovina et al. (2019)	C	Occupational safety	Digital	Y	Y	N
Taillandier and Adam (2018)	J	Disaster management	Digital	Y	N	N
Orbe et al. (2018)	C	Urban planning and design	Physical	Y	N	N
Holzmann et al. (2018)	C	Project management	Physical	Y	N	N
Hamzeh et al. (2017)	J	Lean construction	Physical	Y	N	N
van den Berg et al. (2017)	J	Project management	Physical	Y	N	N
Castronovo et al. (2017b)	J	Structural analysis	Digital	Y	N	Y
Babu et al. (2017)	C	General problem solving	Hybrid	Y	Y	N
George et al. (2017)	C	Construction methods	Digital	Y	Y	N
Axt et al. (2017)	C	Structural analysis	Digital	N	N	N
Goedert and Rokooei (2016)	J	Project management	Digital	Y	Y	N
Cain et al. (2016)	C	General problem solving	Digital	Y	Y	N
Romano et al. (2016)	C	Disaster management	Digital	Y	N	N
George et al. (2016)	C	Equipment operation	Digital	Y	N	Y
Denholm and Stewart (2016)	C	Scheduling	Hybrid	Y	N	N
Hartmann (2016)	C	Project management	Physical	Y	N	Y
Mohd et al. (2015)	J	Occupational safety	Hybrid	Y	N	N
Misfeldt (2015)	J	Project management	Digital	Y	N	N
Lameras et al. (2014)	C	Sustainability	Digital	Y	N	N
Giang et al. (2015)	C	Construction methods	Digital	N	N	N
Dib and Adamo-Villani (2014)	J	Sustainability	Digital	Y	Y	N
Wang et al. (2014)	J	Occupational safety	Digital	Y	Y	N
Sivanathan et al. (2014)	C	Occupational safety	Digital	Y	N	N
Greuter and Tepe (2013)	C	Occupational safety	Digital	Y	N	N
Leong and Goh (2013)	C	Occupational safety	Digital	N	N	N
Dib et al. (2012)	C	Sustainability	Digital	N	N	N
Dickinson et al. (2011)	J	Occupational safety	Digital	Y	N	Y
Oliveira and Duin (2007)	C	Construction methods	Digital	N	N	N

Note: BIM = building information modeling; C = conference paper; and J = journal article.

research in this field and find potential directions for future research and scholarly works to promote novel game-based pedagogical strategies in construction engineering education. We identified four main factors to be considered in future research activities; they are discussed in this section.

Extending Gamification to Various Aspects of Construction Domain

Experiential learning through reflection on what works in particular situations may play a significant role in many aspects of construction engineering and management that rely on firsthand experience. Gamification can facilitate experiential learning in a controlled environment. However, as reviewed in the previous sections, the existing gamified educational solutions have targeted a relatively limited number of areas such as safety, lean construction, and sustainable development. Many other aspects of construction projects, including heavy equipment planning, scheduling, value management, project delivery methods, cost management, and construction material science, have significant potentials to be taught through serious games. For example, in the context of construction scheduling, an interactive game can give students an opportunity to

Table 2. Studies that did not propose a gamified solution

Study category	Studies
Group 1: General discussions	Farghaly et al. (2021), Petrova (2020), Kononova et al. (2019), Gao et al. (2019), Van Breugel (2019), Aubert et al. (2018), Shigeno and Hanns (2018), Campos et al. (2018), Mohd et al. (2018), Freire et al. (2017), Alanne (2016), Osello et al. (2015), Ibrahim et al. (2014), Howard et al. (2010), and Gunning (2008)
Group 2: Creating virtual environment	Walls (2021), Scharpff et al. (2021), Beh et al. (2021), Fonseca et al. (2021), Bükrü et al. (2020), Messi et al. (2020), Selin and Rossi (2019), Holtkamp et al. (2019), Wolf et al. (2019), Sandoval et al. (2018), Hafsia et al. (2018), Eller et al. (2018), Mo et al. (2018), Dinis et al. (2017), Wagner and Rüppel (2016), Vicent et al. (2015), Zhang and Issa (2015), Dawood et al. (2014), Chavada et al. (2012), Karshenas and Haber (2012), and Stothard and van den Hengel (2010)
Group 3: Using limited game elements	Reyes et al. (2021), De Ruyck et al. (2020), González (2018), and Caballero and Niguidula (2018)
Group 4: General technical solutions for game development	Sukhov (2019), Mohd et al. (2019), Radianti et al. (2018), Schatz and Rüppel (2015), Fereire et al. (2015), and Lee et al. (2014)

discover and explore fundamental scheduling methods, such as the critical path method (CPM) and linear scheduling, in various settings with different limitations.

Designing Gamified Solutions Based on Learning Theories

As discussed in the previous section, only 5 studies out of the 49 studies that proposed an educational gamified solution mentioned learning theories, and only 3 of them used a theoretical learning framework to design their proposed game-based learning method. This is a significant limitation in terms of systematic designing and developing game-based pedagogical strategies. Although many researchers and educators in the field of construction may design games based on their teaching experience, there is a significant body of knowledge in learning theories that cannot be ignored when designing novel teaching materials, including games.

Considering the opportunities that a serious educational game may provide to users to explore different options and build upon their knowledge through experience, constructivism has been considered one of the learning theories that can shape the backbone of a gamified learning method. Obikwelu and Read (2012) proposed a constructivist framework specifically designed for learning through gamification. The framework consists of the following six main components:

- Modeling: Using learners' prior knowledge to develop a background related to the learning objectives of the game and build a conceptual model of the process required to attain the game's learning objectives.
- Reflection: Organizing learners' thoughts to connect their preliminary ideas to separate the more important presumptions from less important ones.
- Strategy formation: Forming learners' efforts to develop effective playing strategies to achieve game objectives.
- Scaffolded exploration: Guiding learners' exploration in the game to perceive the impacts and consequences of their actions through various game elements.
- Debriefing: Describing the events that occurred in the game alongside discussing mistakes and corrective actions by learners to help them link their discoveries with their previously existing schema and knowledge.
- Articulation: Facilitating communication among learners to help them share their acquired knowledge and gain ideas to promote collective goals of understanding.

To design novel gamified educational solutions scientifically, it is critical to increase the awareness of learning theories and state-of-the-art research in that field in the construction research community. Multidisciplinary research and scholarly works through collaboration between the construction engineering community and experts in education and social science is a key toward achieving that goal. However, review of the identified publications does not indicate that a strong relationship has emerged among these communities. Only 9 studies out of the 49 studies proposing an educational gamified solution included an author affiliated with an education or social science department. Encouraging such collaborations is vital for future research and development investments in this area. Research funding agencies, such as the National Science Foundation (NSF), also support this type of collaboration through various programs. The NSF Professional Formation of Engineers: Research Initiation in Engineering Formation (PFE: RIEF) is an example that aims to prepare and train engineering researchers for leading social science and educational research through collaboration with experienced mentors in those fields.

Using Gamification to Promote Learning at Scale

Digital serious games for education can considerably contribute to learning at scale systems. These educational approaches aim to create technology-mediated learning environments for large-scale active learners with few experts available to guide their progress or respond to individual needs (Roll et al. 2018). Such systems can overcome temporal and spatial limitations and provide high-quality learning opportunities for many people around the world. The disruptions in the traditional educational systems caused by the COVID-19 pandemic also showed the necessity of these novel approaches. Learning-at-scale approaches promote equity, accessibility, and inclusion.

To effectively and efficiently contribute to learning-at-scale systems, a game needs to be smart. A smart game uses artificial intelligence (AI) and machine learning methods to actively monitor the performance of the users via analyzing the log files and guiding them via customized feedback and dynamic scenario-based objectives that can be adjusted based on user actions. Such games can work as an automated, independent, and on-demand platform for education. In addition to their potential to educate a large number of learners, AI-enhanced games can provide a more flexible environment for guided active exploration in which a learner has more opportunities to make various decisions and observe their consequences freely.

Games for Vocational Training

The fourth industrial revolution is changing every aspect of the construction industry. It is critical to train and prepare construction professionals to effectively work in the rapidly changing digital era, efficiently interact with new technologies, and gain the required skills. Recent studies, such as that by OECD (2019), indicated that adult professionals could learn better through modular learning materials that are integrated into their daily professional activities. Customized game-based vocational training modules that help professionals learn how to interact and work with new technologies can be a basis for future research and scholarly activities. Novel training approaches, such as synchronous learning (Finkelstein 2006), may help design digital games for vocational training.

Conclusion

In this study, we conducted a scoping review to understand the extent, range, and nature of the existing research in gamification for construction engineering education, identify limitations, and determine potential directions and considerations for future research and scholarly works in this field. We designed and executed the scoping review using a search protocol based on the PRISMA-ScR method. The review process consisted of six main steps: (1) defining the inclusion eligibility criteria, (2) determining the information source database, (3) designing the search strategy, including the search queries, (4) conducting the search and identifying the relevant documents, (5) reviewing the full manuscripts for data extraction, and (6) synthesizing the extracted information.

Any technical article that discussed the application of gamification in construction engineering education and training was included in the review if written in English. We searched the Scopus bibliographic database using queries targeting phrases related to gamification and the construction industry in the title, abstract, or keywords of the publication. Through the search process, we identified 103 relevant documents. During the review process, we extracted two sets of information from each relevant publication. The first set included basic attributes of the publications, including the type of document (e.g., peer-reviewed journal paper, conference proceedings, and book chapter), publishers, author affiliation, and publication year. The second set of information concentrated on the contents of the documents and concerned a wide range of factors, such as whether the study developed a novel gamified solution if the proposed gamified solution in a publication was designed based on a learning theory, and specific areas in the construction education and training domain that were targeted by the gamified solutions.

Using the collected information, we analyzed existing research and identified its limitations and knowledge gaps. Based on these findings, we proposed four critical factors to be considered in future research activities. These factors include (1) extending gamification to various aspects of the construction domain, such as scheduling and heavy equipment planning that offer significant potential for experiential learning, (2) designing gamified solutions based on learning theories, (3) using AI-enhanced smart games to promote learning at scale, and (4) designing modular games integrated into the daily tasks of construction professionals for vocational training.

This study sets the stage for developing systematic plans to direct future research and scholarly works to design and implement game-based pedagogical strategies for education and training in the construction industry. The outcomes of this study will help construction researchers and educators better understand the state-of-the-art advancements in gamified educational solutions and systematically plan for future research endeavors to address the existing limitations and knowledge gaps.

Although we closely followed the PRISMA-ScR process to design our search and review protocol to conduct a transparent and rigorous scoping review, this study is still subject to inherent limitations. The first potential limitation is linked to the source database, Scopus. Although as of this writing, Scopus indexes more than 36,000 titles from more than 11,000 publishers, including major peer-reviewed journals and conference proceedings in construction and related fields as well as education and social science, still there is a chance that some relevant publications from sources not covered by Scopus exist. However, it should be noted that, considering the overarching objective of this scoping review, the identified 103 articles sufficiently depicted the extent of the research in this field and its limitations. The second potential limitation is related to our search queries. We defined the target keywords for search queries based on our experience and observations in the literature; however, there might be studies that took advantage of gamification elements without directly labeling that.

Data Availability Statement

All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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