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Synergies between Serious Games and Production Planning and Control: A Systematic Literature Review

Abstract

Purpose: This study aims to identify the synergies between Serious Games (SGs) and Production Planning and Control (PPC) education, identifying key factors for SG development in PPC contexts and assessing methods for evaluating in-game performance and user experience.

Study design/methodology/approach: A systematic literature review was conducted using the Scopus database, identifying 52 relevant studies published up to September 2024. The review focused on SGs in PPC-related domains such as construction, manufacturing, and project management.

Findings: Key findings reveal that SGs can significantly improve student engagement, knowledge retention, and skill development in PPC and related domains such as project management, construction, manufacturing, and software engineering. The study outlines crucial factors for developing SGs in PPC education, including game scenario design, player roles, and uncertainty simulation. Two primary assessment methods were identified: in-game performance and user experience evaluation. Based on these findings, a conceptual framework is proposed to guide the development and assessment of SGs in PPC contexts.

Originality: This paper presents a novel integration of SGs into PPC education, addressing the growing complexity of production environments and the need for enhanced decision-making skills. The proposed framework offers a comprehensive approach to developing and implementing SGs in PPC education, potentially transforming how complex PPC concepts are taught and applied in practical settings.

Keywords: serious games; gamification; production planning and control; management education; game development; user experience

1. Introduction

The education of Production Planning and Control (PPC) faces numerous challenges due to the increased complexity of products and the shift from traditional manufacturing to knowledge-based approaches (Kubat et al., 2007). Traditionally, tools such as mathematical programming, network analysis, and heuristic approaches have been used to teach PPC (Olhager and Wikner, 2000). Despite their usefulness, these traditional educational methods often fall short of addressing the educational challenges posed by complex and uncertain production environments. They fail to fully engage students and capture the complexities of human decision-making processes that are critical in real-world PPC scenarios. Conventional approaches seldom explore the impact of human decision-making on the implementation of PPC functions (Jan et al., 2010), often assuming rational decision-making behaviour and perfect understanding. However, Bendul (2019) and Bendul and Knollman (2016) emphasise the crucial role humans play in PPC decision-making. Therefore, there is a need to explore alternative approaches that combine human decision-making with simulated PPC environments. To address the growing complexity and need for real-world decision-making skills in PPC education, SGs provide immersive and interactive learning experiences. By simulating real-world scenarios and uncertainties, SGs enhance students' understanding and application of PPC principles. SGs offer enhancement in student engagement, understanding, and retention by simulating realistic work environments and decision-making processes.

Serious Games (SGs), are understood as "games in which education (in its various forms) is the primary goal, rather than entertainment" (Michael and Chen, 2005, Sailer et al., 2017), can be used for simulating more realistic work environments by linking real-world information, objects, virtual roles (Wang et al., 2016) and complicated decision-making processes (Rissanen et al., 2020). Many studies in different domains, such as project management (Rumeser and Emsley, 2019), manufacturing (Rodrigues et al., 2012), and construction (Tagliabue et al., 2020), have demonstrated the potential of SGs for education, training and enhancing decision-making skills of students and industry practitioners (Rissanen et al., 2020), thus enabling higher performance of those domains. However, SGs have not been widely utilised in the context of PPC education, even though a few studies have identified the potential of SGs for transferring knowledge in PPC (Brauner et al., 2016; Warmelink et al., 2020; Thürer et al., 2020; Andari et al., 2022)..

Recent research demonstrates that SGs extend beyond traditional educational settings, offering valuable applications in diverse industrial contexts. These include assembly line operations, construction management, software project management, and sustainable project management (Hellström et al., 2023, Ilbeigi et al., 2024, Khanzadi et al., 2019). These fields share similar challenges in engaging workers and students, improving productivity, enhancing situational awareness, and facilitating continuous learning.

In order to address the above-identified gap in the PPC education literature across multiple domains including manufacturing, construction, and project management, this research aims to identify key features and best practices for the development and evaluation of SGs in the PPC education context by answering the following research questions:

RQ 1: What are the factors to consider when designing and developing SGs for PPC education?

RQ 2: What assessments can be incorporated to evaluate In-game performance and overall user experience when implementing SGs in PPC education?

This paper introduces a novel conceptual framework for integrating Serious Games into PPC education. Unlike previous studies, which primarily focus on isolated aspects of SGs or PPC, our framework systematically combines these elements to provide a comprehensive approach. This integration is expected to enhance student engagement, improve decision-making skills, and bridge the gap between theoretical knowledge and practical application. By doing so, our study contributes significantly to the existing body of knowledge, offering practical solutions for educators and advancing the field of PPC education.

This paper consists of six sections. Following this introduction section, the second section presents the background information related to this study, including the critical functions of PPC and SGs. The third section explains the research method and incorporates a systematic literature review. The fourth section is devoted to data analysis and synthesis. The results are interpreted in the fifth section by proposing a conceptual framework for developing and evaluating SGs in the PPC context. Finally, conclusions are presented, including the study's limitations and future research.

2. Background

The integration of SGs into educational settings has shown promise in various domains. However, practical steps for their implementation in PPC education have not been well-documented. This paper aims to fill this gap by providing a structured approach for educators to follow, ensuring effective and engaging learning experiences. This section provides background information about the fundamentals of the topics covered in this paper.

2.1. Production planning and control (PPC)

PPC is defined as "the coordination of a series of functions according to a plan which will economically utilise the plant facilities and regulate the orderly movement of goods through their entire manufacturing cycle from the procurement of all materials to the shipping of finished goods at a predetermined rate" (Aswathappa and Bhat, 2009). Several classifications of PPC functions can be found in the literature with two prominent frameworks offering complementary perspectives.

Kumar and Suresh (2006) grouped all the tasks of PPC into three main categories: (1) pre-planning, (2) planning, and (3) control. The pre-planning function can be subdivided into product design, process design, flow design, and demand forecasting. Planning consists of planning 4Ms (materials, methods, machines, and man), routing, scheduling, and estimating. Control's primary function comprises dispatching, inspection, expediting, and evaluating subfunctions.

In comparison, Aswathappa and Bhat (2009) present an alternative three-part classification: (1) planning, (2) operations, and control. Planning can be understood as selecting several alternative options that represent the best utilisation of available resources to accomplish desired production objectives most economically and efficiently. Operations are the execution of the developed plan. In the control stage, the performance of the implementation of the production plan is monitored through feedback and is compared to the defined milestones determined in the planning stage. This comparison aims to take corrective actions to improve the performance or adjust plans and targets to fulfil the production goals.

2.2. Serious Games (SGs)

Games are intentionally designed to challenge the human imagination (Arnold et al., 2013). According to Abt (1970), participants assume realistic characters, deal with problems, formulate strategies, make decisions, and receive feedback quickly based on their actions when playing a game. Several classifications of game design elements can be found in the literature. Schell (2008) defines four essential aspects of a game: (1) mechanics, (2) story, (3) aesthetics, and (4) technology. Game mechanics explain how the player can achieve the game's goal using specific rules and procedures. The story of a game is a series of events the player experiences as the game progresses. Those events may be linear or branching based on the player's selections. Aesthetics relates to how the player can see, hear, smell, and feel throughout the gameplay. Technology facilitates connecting story, aesthetics, and mechanics to make the game possible to experience. Sailer et al. (2017) reported seven typical game design elements, as shown in Table I.

Table I: Game design elements (Sailer et al., 2017)

SGs are known as educational or training games. The main objective of these types of games is to train, educate or inform gameplayers with fun, if possible (Calderón et al., 2018). SGs allow untrained people to understand a problem situation in a simple manner without the costs of failure or real-world effects (Michael and Chen, 2005).

SGs have been classified in various ways and can be identified in different forms. Generally, SGs can be grouped into digital and non-digital games. In terms of teaching technical skills, digital games are more effective compared to non-digital games, which are more useful for soft skills training (Despeisse, 2018). Calderón and Ruiz (2015) recognised eight types of SGs, as presented in Table II.

Table II: Types of SGs (Calderón and Ruiz, 2015)

In addition, SGs that use augmented reality technology, where a digital image is superimposed onto the player's view (McMillan et al., 2017, Stefanidi et al., 2020), can be found in the literature. Immersive virtual reality SGs, which provide a hands-on experience to the player (Connolly et al., 2012) with improved perception and engagement compared to videos through a fully immersive environment, can also be found in the literature. Moreover, mixed reality technology is used to link the real environment with a virtual world to generate a new space (Galvão et al., 2011).

In the context of the Architecture, Engineering and Construction (AEC) industry, SGs have shown significant potential for enhancing communication and decision-making processes. Pour Rahimian et al. (2020) highlight that SGs provide a way for individuals without specialised training to grasp complex situations in a simplified manner, without the risks or consequences associated with real-world scenarios. This ability to simulate complex scenarios in a low-risk environment makes serious games particularly valuable in construction planning and client communication. The application of serious games in construction has been evolving with technological advancements. Potseluyko et al. (2022) note that BIM, gamification, and Virtual Reality technologies are increasingly being utilised to support Design for Manufacture and Assembly (DfMA) processes. This integration of BIM data with game-like interfaces creates new possibilities for interactive design and planning tools (Özener, 2024). The application of serious games in construction has been evolving with technological advancements. Moreover, serious games can significantly enhance client engagement in construction projects. As Potseluyko et al. (2023) demonstrate, integrating game-like elements with BIM can facilitate easier data presentation to clients, potentially leading to improved customer satisfaction, increased confidence, and higher sales figures. This suggests that serious games can not only improve technical processes but also have tangible business benefits in the construction industry.

As discussed in this background section, the complexities of both PPC functions and SGs highlight a significant opportunity for their integration. As production environments become increasingly complex and dynamic, traditional educational methods for PPC are often insufficient to prepare students for real-world challenges. SGs offer a promising solution by providing immersive, risk-free environments where learners can experience the intricacies of PPC decision-making, understand the consequences of their choices, and develop both technical and soft skills required in modern production settings. This integration becomes particularly relevant as industries increasingly recognize the human factors in PPC, which conventional teaching approaches struggle to address. The following sections explore how this integration can be effectively achieved through systematic analysis of the existing literature.

3. Research method

In order to explore the possibilities of utilising SGs in the PPC context, there is a need to gain a systematic understanding of the use of SGs in domains closely related to PPC. Consequently, we conducted a Systematic Literature Review (SLR) of research in PPC domains such as construction, manufacturing, and project management. These three domains were selected as they represent the primary application areas for PPC principles in both industry and academia (Herrmann, 2006; Koskela, 2000), with manufacturing being the historical origin of PPC methodologies (Hopp & Spearman, 2008), while construction and project management have extensively adapted these approaches to their specific operational contexts (Ballard & Howell, 2003; Abdelmegid et al., 2021). Additionally, these domains share common PPC challenges despite their differences, enabling meaningful cross-domain knowledge transfer (Koskela & Howell, 2002; Bertelsen, 2003). Our preliminary review also indicated that these domains contained the richest body of literature on SGs applications related to PPC functions, offering sufficient material for a comprehensive analysis with broad educational relevance.

The SLR procedure follows a reproducible, methodical and transparent approach to select the most appropriate studies that address the review questions and provide an overall assessment of the area under review (Borrego et al., 2014). Also, SLR articles synthesise grey and peer-reviewed literature (Thomé et al., 2016). Based on our initial literature review, we observed an increasing number of SLRs being conducted in PPC-related contexts (Bueno et al., 2020; de Souza Costa et al., 2021), indicating growing scholarly interest in systematically analysing this field.

Several approaches have been developed to guide a systematic literature review, such as PRISMA (preferred reporting items for systematic reviews and meta-analysis) (http://www.prisma-statement.org) (Moher et al., 2009), a five-step approach reported byKhan et al. (2003), and a methodology developed for SLR applicable to the field of engineering and diverse multidisciplinary areas by Borrego et al. (2014). This research employs the complete guidance developed by Thomé et al. (2016) for conducting SLRs for operations management because PPC is primarily discussed under operations management (Aswathappa and Bhat, 2009, Kumar and Suresh, 2006). Figure 1 demonstrates the main stages of this methodology.

Figure 1: Research design (Source: Authors own work)

3.1. Planning and formulating the problem

The main objective of this stage is to develop the proposal for the review. The first author developed a research plan that included: (1) defining the scope and objectives of the SLR; (2) establishing clear research questions focused on identifying factors for SG development in PPC contexts and assessment methods for these games; (3) determining appropriate databases and search strategies; (4) developing inclusion and exclusion criteria; and (5) creating a data extraction and synthesis framework. This plan was developed with the assistance of the second author, who drew on their expertise conducting SLRs. The complete plan was then reviewed and validated by the full research team to ensure methodological rigour and alignment with the research objectives.

3.2. Literature search

This stage began with the selection of databases. We used Scopus to select appropriate resources for this review. Scopus is well recognised database that indexes the most significant and relevant literature on SGs topics (Feng et al., 2018). Our decision to focus on Scopus was based on its comprehensive coverage of peer-reviewed literature in fields relevant to our research, including engineering, computer science, education, and management. While using multiple databases could potentially provide broader coverage, studies have shown substantial overlap between major databases in these disciplines (Mongeon and Paul-Hus, 2016; Visser et al., 2021; Martín-Martín et al., 2021). To mitigate the limitations of using a single database, we implemented rigorous backward and forward snowballing techniques (Wohlin et al., 2022) across several databases (Google Scholar, ResearchGate, and publishers' digital libraries), which yielded an additional eight publications not initially captured in our Scopus search.

Next, keywords for the review were determined. First, we tried to find the most relevant publications with the use of different combinations of the following keywords: “serious games” or “gamification” and “production planning and control” and “education”, then “serious games” or “gamification” and “production planning” and “production control” and “education. Nevertheless, only a small number of articles were found using those keywords, which shows the unpopularity of using SGs in the PPC context to date. Then, we defined a new set of keywords considering application areas of PPC with synonyms of those areas, namely, “production,” “manufacturing,” “construction,” “fabrication,” “project,” and “operations”. We also considered the essential functions of PPC, which were discussed in the background section, with the alternative words for those functions.

Publications were searched based on three major categories, which are given in Table III: (1) the first column: serious games or gamification; (2) the second column: serious games’ application areas that are related to PPC functions; and (3) third column: key functions of PPC with widely used synonyms of those functions. Education-related keywords were not included to expand our investigation beyond education to incorporate other applications of SGs, such as training and professional development.

Table III: List of keywords. (Source: Authors own work)

The keywords were used with the “Title, abstract, keywords” criteria to find the most relevant publications from Scopus. The last search iteration was conducted in September 2024, including all publications up to this date without specifying a publication period. The search was limited only to articles published in English, with no geographical restrictions applied. Accordingly, 2131 research papers were found. Then, abstracts of those publications were evaluated with the inclusion criteria displayed in Table IV.

Publications whose content does not match the inclusion criteria were removed. Consequently, 298 publications were selected for full-text scanning. Next, the full text of those selected articles was scanned, and 242 of those articles which were not helpful in achieving the objectives of this research, were eliminated based on the exclusion criteria listed in Table IV. With the remaining 48 publications, backwards snowballing, in which relevant articles are searched from the reference list of selected articles, and forward snowballing, in which relevant documents are found based on articles cited in the selected publications, were used to gather missing but relevant articles for this research (Jalali and Wohlin 2012). For this snowballing process, we consulted multiple databases and sources to locate and retrieve the full texts of potentially relevant articles. For forward snowballing, we primarily used Google Scholar to identify papers that cited our selected publications. For backward snowballing, we examined the reference lists of our selected publications and searched for these cited works across multiple sources including Google Scholar, ResearchGate, and publishers' digital libraries. This approach to snowballing enabled us to identify eight additional publications that met our inclusion criteria but were not captured in our initial Scopus search. Finally, 52 publications were selected for data collection and quality evaluation. The process can be seen in Figure 2.

Table IV: Inclusion and exclusion criteria. (Source: Authors own work)

Figure 2. Identification, Screening, and Selection process of the systematic literature review (Source: Authors own work)

3.3. Data collection and quality evaluation

There were two data collection objectives from the selected literature: to identify the factors to consider when developing SGs in the PPC context and to recognise types of assessments that can be utilised to evaluate in-game performance and the overall user experience of PPC SGs. Accordingly, the content of selected papers was investigated, focusing on those objectives.

The next step was evaluating the quality of selected publications. According to Cooper et al. (2009), the quality of a study is the match between the study's aim and its design and implementation. A method which involves a scoring procedure used in several systematic literature reviews (Connolly et al., 2012, Feng et al., 2018), was adopted to assess the quality of eligible publications. The appropriateness of each publication for this research was evaluated using the following questions.

1. How appropriate is the publication with essential factors for developing SGs for PPC?
2. How relevant is the paper for assessing the in-game performance of PPC SGs?
3. How well does the publication align with the assessments pre-determined to evaluate the overall user experience of PPC SGs?

Each of these questions is designed to have three possible answers with a clearly defined score: Low – 1, Medium – 2, and High - 3. Each paper was evaluated based on these questions and given a score. Then, the total score was calculated for each article. Based on the scoring system, the total score of a publication can vary from (1+1+1 = 3) to (3 + 3 + 3 = 9). Basic descriptive statistics of the score are demonstrated in Table V. It is important to note that all 52 papers that passed the inclusion/exclusion criteria were retained in the analysis regardless of their quality score. No papers were excluded based on quality score alone. Rather, these scores were used to understand the relative strength of evidence across the reviewed publications and to provide context for the synthesis of findings. This approach ensured that all relevant contributions to the field were considered while maintaining awareness of the varying methodological rigor across studies.

Table V: Quality evaluation (Source: Authors own work)

3.4. Maintaining reliability of searching and coding

Reliability in this context is understood to be the replicability of selecting the most relevant publications and extracting useful information for the research (Thomé et al., 2016). Accordingly, the literature search process was repeated in several iterations to enhance the accuracy of including papers in this study. Also, reliability describes the level of agreement between research team members regarding choosing articles and data gathering (Thomé et al., 2016). The second author validated the search results, identified 4 more articles, and agreed with the research team on critical decision-making points, including selecting articles and defining themes to maintain reliability until all the team members were in agreement.

4. Data analysis and synthesis

This section presents the results of the SLR and analyses them to define the essential elements to develop SGs for PPC education. Recent literature investigated SGs elements for specific objectives. For example, Feng et al. (2018) discovered critical elements of building immersive virtual reality SGs for evacuation studies. As recognised by Feng et al. (2018), identification of these factors is characterised by more domain-specific and objective-oriented features, such as *teaching methods, navigation solutions, and narrative methods*. Furthermore, Van der Zee (2014) identified essential elements, such as the *conceptual simulation model, simulation coded model, and simulation use model*, when developing a framework for simulation-based serious games for operations management. Similarly, our research also focuses on a specific goal: identifying key factors to guide the development of SGs for the PPC context.

After a thorough analysis of the selected literature, we identified recurring patterns and key elements that appeared consistently across multiple studies. We conducted a thematic analysis following the six-phase approach outlined by Braun and Clarke (2006): (1) familiarization with data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report.

Through thematic analysis and content categorisation, seven primary aspects emerged as critical components in developing and implementing serious games for PPC education. These aspects were not predetermined but rather emerged from the synthesis of the reviewed papers, representing the most frequently discussed and emphasised elements across the literature. These seven aspects are: (1) game scenario; (2) players' roles and their activities; (3) simulation of uncertainties; (4) time limitation for the gameplay; (5) strategies to make the SG ready for the implementation; (6) assessment of in-game performance; and (7) assessment of user experience. Each aspect was further analysed to identify best practices and considerations for SG development in PPC contexts. The following sub-sections present the results related to these aspects. It is important to indicate that some of the identified papers did not clearly include all of these aspects so we only present the results as available in the selected literature.

4.1. Game scenario

Table VI demonstrates the associated game scenarios in the selected articles. When analysing the scenarios, it is clear that game scenarios have been built around industry-specific real-world situations that employees face, such as completing a software project (Galvão et al., 2011), completing a construction project (Misfeldt, 2014), and completing a new product development project (Rumeser and Emsley, 2019). Analysing game scenarios from the literature, we find that SGs tailored to specific PPC functions (e.g., scheduling, resource allocation) provide targeted learning experiences that improve students' operational decision-making skills. For instance, games that simulate lean manufacturing principles help students understand waste reduction strategies in production planning. Although a particular industry has many functional areas, a particular game focuses only on a limited number of functions. For instance, we found many construction-related SGs in different areas, such as constructing a multi-story apartment, pavilion, or special-purpose building. Also, there is a clear focus on specific themes within a selected application area. For example, in construction SGs, the TACT game (Denholm and Stewart, 2016) focuses on the critical path method and Earned Value Analysis. Students who participated in the TACT game were able to apply these methodologies more effectively in their final-year projects, as indicated by higher project completion rates and better adherence to project timelines. The LEAPCON game (Sacks et al., 2007), which focuses on lean principles, resulted in students achieving a deeper understanding of lean construction techniques, leading to more efficient project execution and reduced waste in practical settings. Consequently, we can conclude that when designing the story of SGs for the PPC context, we should consider three aspects: (1) the game story should be developed around a particular industry; (2) the story should focus on a particular application area within that industry; (3) the story should be built on a selected theme.

Table VI: Features of game scenarios. (Source: Authors own work)

4.2. Players' roles and main activities

Table VII reports players' roles and main activities during the gameplay. When analysing players' roles, it can be recognised that roles represent real-world professions, such as software project manager, construction manager job site superintendent, and quality controller. Gameplay activities can be assessed as representing essential functions defined in real-life professions, such as project planning, human resources management, and follow-up actions. Therefore, we argue that when determining essential elements to develop SGs for the PPC context, it is vital to define the roles of players in professions in the real PPC context so as to better represent reality. Also, we conclude that the number of activities in the gameplay should be determined based on the nature of the industry, application area, and the themes considered for the SG.

Table VII: Players' roles and leading activities. (Source: Authors own work)

4.3. Simulation of uncertainties

Uncertainties are practical in game design because they enhance the realistic nature of the game by creating challenges and a joyful environment for the players (Galvão et al., 2011). According to the literature review, the simulated uncertainties should be similar to the frequently observable problems faced by professionals in the industry under study; for instance, defects (Maxim et al., 2016), absenteeism of employees (Galvão et al., 2011), and weather (Lee et al., 2015). Agati et al. (2024) introduced uncertainties in their gamified system for manual assembly lines by simulating varying production rates and quality issues. Ilbeigi et al. (2024) incorporated uncertainties in their construction scheduling game through randomised events that affect project timelines and resource availability. Armenia et al. (2024) incorporated unexpected events and stakeholder behaviour changes in their project management board game.

In addition to simulating real-world problems, uncertainties can be generated through various sources. For example, Galvão et al. (2011) simulated uncertainties, such as creating problems through rumours between employees and removing employees from the system based on a health condition generated within the game system. Similarly, in the SG reported by Zwikael and Gonen (2007), uncertain events were drawn from a database using the Monte Carlo Method, which is pre-defined and generated by the game. Also, uncertainties can emerge because of players' performance during the gameplay, such as longer operational time and production defects (Maxim et al., 2016), learning curve (Lee et al., 2015), selection of design variation by clients (Sacks et al., 2007), and problems created by an opposing team (Misfeldt, 2014). Moreover, in the SG proposed by Tagliabue et al. (2020), uncertainties, such as creating low visibility in one workstation and redistribution of tasks, have been simulated by the facilitators of the game. As a result, we can identify simulated real-world problems or uncertainties that can be simulated by players, the game itself, and facilitators. Figure 3 summarises the evidence of simulating different uncertainties reported in SGs within the selected publications.

Figure 3: Simulation of uncertainties - Number of publications reporting each type of uncertainty simulation method (Source: Authors own work)

4.4. Time limitation for the gameplay

When considering factors to develop SGs for the PPC context, it is vital to determine a time limitation for gameplay (SG evaluation). To determine the most common interval for gameplay, we present the summary of reported durations of SG experiments in selected publications in Figure 4.

Figure 4: Reported durations for experiments (Source: Authors own work)

With respect to reported durations of simulations, it should be noted that some assessments take more than one day (Castronovo et al., 2022, Law, 2019). However, most studies generally take less than or equal to 3 hours (Drappa and Ludewig, 2000, Heikkilä et al., 2016). Experiments that have taken more than one day have considered some special requirements, such as the study's objective and complexity, scope, and nature of the design of the experiment. For example, in the study reported by Law (2019), the whole investigation was conducted over four days because the study simulated a realistic product development project covering all the phases of a project, and was based on the action-learning approach to educate project management students. Hellström et al. (2023) reported that most project management serious games in their review had gameplay durations ranging from 1 to 4 hours. Jääskä and Aaltonen (2022) found that shorter game sessions (30-60 minutes) were more effective for maintaining student engagement in project management education.

According to Figure 3, some studies report durations for both experiments and assessments, while others report durations only for the experiment phase. For studies not having unique requirements, durations for the experiments (gameplay) varied from 11 minutes to 120 minutes, while durations reported for the whole experiments, including assessments, ranged from 90 minutes to 180 minutes. According to these published and successfully implemented SGs, we can conclude that an SG should be designed so players can play the game within 2 hours. Furthermore, surveying participants about the user experience should be limited to less than 1 hour. Moreover, time limitations must be determined based on the whole experiment's unique requirements, such as complexity, scope, and nature of the design of the experiment, without harming its validity and reliability.

4.5. Strategies to make the SG ready for the implementation

Several studies reported various strategies to make the SG ready for implementation. For example, Rumeser and Emsley (2019) built mock-up games for two SGs and gained initial approval from the corresponding course administrator. Calderón et al. (2018) also validated the SG they used in their research with the help of subject experts. Similarly, verification and validation were done by Lee et al. (2015) on their SG before its utilisation. Zwikael and Gonen (2007) conducted a pilot study with the help of 87 undergraduate students to test the validity and reliability of their SG before its use. Maxim et al. (2016) reported having the development team complete a usability checklist related to their SG by before gameplay. Apart from activities related to verification and validation, allowing appointed trainers to customise game scenarios is another approach reported in two studies (Calderón et al., 2018, Zwikael and Gonen, 2007). These approaches suggest the importance of minimising the negative impact of improper game design on the implementation objectives of SGs.

In addition, some studies reported different approaches during the preparation stage for the game implementation. Rachman and Ratnayake (2017) delivered an introductory course about Lean, Kanban, and risk-based inspection before the start of gameplay. Similarly, Calderón et al. (2018) provided the background knowledge needed for playing their SGs to participants who were students in a project management course. In addition to providing the required knowledge through an introductory course, some researchers provided detailed instructions before starting the gameplay. An instructor explained the SG's objectives in the study of Wangenheim et al. (2012). Likewise, Law (2019) provided fundamentals of project management to players before starting their game. Vanhoucke et al. (2005) gave their participants a general introduction to the study and critical path methodology. One study reported asking players to watch an introductory video related to the SG (Caserman and Göbel, 2020). Zwikael and Gonen (2007) allowed participants to use a game-related manual to prepare for the gameplay. Two publications also reported exposing participants to a game-related tutorial (Galvão et al., 2011, Maxim et al., 2016). These reported approaches help remove confounding effects related to inadequate knowledge about the gameplay.

Furthermore, several variations on these methods have been reported in selected publications. Tagliabue et al. (2020) provided an instruction manual that could be used during gameplay to remind players of the guidelines whenever they needed it. Lino et al. (2015) allowed players to see a particular chapter and sections in the Project Management Body of Knowledge (PMBOK) to find detailed information related to a specific area during the gameplay. In addition to reading-based support, some studies reported using individuals to help players during gameplay. Denholm and Stewart (2016) used a tutor to provide feedback to participants during the gameplay; Lee et al. (2015) used an instructor to coordinate the game session in their study; and Heikkilä et al. (2016) utilised an instructor to clarify the rules at different stages of the game. Moreover, SGs reported in one study allowed features useful for the players to be enabled for self-support during gameplay. Caserman and Göbel (2020) displayed keyboard functions on the gameplay screen, and players could access the help section during gameplay. Hellström et al. (2023) emphasised the importance of aligning game objectives with course learning outcomes. Ingason and Eskerod (2024) recommended creating detailed facilitator guides to ensure consistent game implementation across different instructors. Gasca-Hurtado and Machuca-Villegas (2024) conducted pilot tests with both students and industry professionals to refine their game design.

Table VIII contains all the reported strategies in the selected publications. We recognise that these strategies could be implemented at three different stages: (1) during the development of SGs, (2) during the organisation of the gameplay and just before the session, and (3) during the gameplay.

Table VIII: Strategies to make SGs ready for implementation. (Source: Authors own work)

We can conclude that appropriate strategies should be implemented during the game development process, before and during the gameplay, to gain the maximum benefits of implementing PPC SGs.

4.6. Assessment of in-game performance

We found several studies that reported how players perform while they play the game (in-game performance) to evaluate SGs. Figure 5 summarises how data concerning in-game performance was collected in the selected publications.

Figure 5: Method of data recording (Source: Authors own work)

We identified several SGs designed for gameplayers to record in-game performance manually during gameplay. Rachman and Ratnayake (2017) arranged the game so that players could manually record their game-related data, such as lead time in unit cards. Tagliabue et al. (2021) instructed players to record time using a stopwatch. During gameplay, von Wangenheim, Savi, and Borgatto (2012) asked players to manually enter project progress in a performance report. In the study conducted by Castronovo et al. (2022), all participants were provided with recording sheets on which they recorded game data, such as planned cost, actual cost, duration of the construction, and labour efficiency score. Denholm and Stewart (2016) utilised a tutor to record and evaluate player performance, such quality of project plans the players had developed. Also, the tutor manually entered player project-related decisions into a computer. Sacks, Esquenazi, and Goldin (2007) recorded in-game performance data: completed apartments, defective apartments, time to finish the first apartment, WIP, throughput, cash flow, and cycle time. We note that players and game facilitators participated in this activity when considering manual data recording.

In addition, some studies reported specific approaches to storing in-game performance data automatically. Galvão et al. (2012) designed a particular module to record productivity statistics, players' actions, game score, ranking, and game progress. Calderón, Ruiz, and O'Connor (2018) recorded project-related data, such as time, cost, and actual and planned value, within the game. Rumeser and Emsley (2019) enabled a system for automatically recording data, such as players' decisions, time, and costs. Lee, Nikolic, and Messner (2015) stored game-related data in the MS Access database. Tagliabue et al. (2021) designed an IoT-enabled system with a smartphone app to capture time, location, and light intensity data. Lino et al. (2015) designed their SG to automatically record in-game performance data, including time, cost, and schedule information. Martinez et al. (2023) used eye-tracking technology to measure players' situational awareness during gameplay. Agati et al. (2024) implemented real-time performance feedback mechanisms within their gamified assembly line system. Jääskä et al. (2021) incorporated peer evaluation as part of the in-game performance assessment. In summary, researchers have used various methods to record game-related data, such as special modules, databases, and mobile apps.

According to the publications reported on in-game performance, it is clear that these are very similar to performance measures in real-world operations. project Time, project cost, and quality (Galvão et al. 2012), and all quantitatively reported measures.

After examining the reported in-game performance measures, we could recognise two types. One is game progress-related measures, such as production time (Tagliabue et al. 2021), and Planned Percent Complete Gonzalez-Moret et al. (2015). The other is player status-related measures, such as the number of correct and wrong decisions made by players (Lino et al. 2015) and defective products (Sacks, Esquenazi, and Goldin 2007). We note that seven studies reported both measures, as shown in Figure 6.

Figure 6: Types of in-game performance measures (Source: Authors own work)

When studying in-game performance assessment methods in selected and reported publications, we recognised that those methods could be grouped into three categories, as depicted in Figure 7: industry-specific methods, special project scores and general statistical methods. Several studies reported summarising corresponding data using industry-specific tools and techniques, such as resource utilisation charts, control charts, lead time distribution charts, cumulative flow diagrams (Rachman and Ratnayake 2017), and EVA (Denholm and Stewart, 2016, von Wangenheim et al., 2012). Also, a specific project score was defined based on collected quantitative data in some publications (Castronovo et al., 2022, Galvão et al., 2011, Lino et al., 2015). Furthermore, many studies reported using general statistical tools and methods, such as computing summary measures, graphical presentations (Galvão et al., 2011, Rumeser and Emsley, 2019), and hypothesis tests (Castronovo et al., 2022, Rumeser and Emsley, 2019). We recognised six publications that reported a combination of the methods mentioned above to assess the in-game performance of SGs.

Figure 7: Number of publications that reported different types of in-game performance assessment methods. (Source: Authors own work)

4.7. Assessment of user experience

User experience is defined as the collective consequences felt by users before, during and after interacting with a system or a product (Hartson and Pyla, 2018). This section summarises critical aspects, such as user experience measures, data recording tools and analysis methods related to SG implementations.

Player user experience was collected in three ways; namely, questionnaires (Heikkilä et al., 2016, Zwikael and Gonen, 2007) and interviews (Denholm and Stewart, 2016, Misfeldt, 2014) and discussions (Lee et al., 2015). Most researchers used post-game questionnaires to capture the user experience of SGs. The post-game questionnaire used by Castronovo et al. (2022) had been modified from a developed instrument from previous research. Tumpa et al. (2024) identified "perceived learning" as an important user experience measure in project management games. Leite et al. (2023) emphasised the importance of assessing ethical considerations and potential negative impacts of gamification in manufacturing and construction settings. Ruiz de la Torre Acha et al. (2024) employed physiological measures, such as heart rate variability, to assess user engagement and stress levels during gameplay.

User experience data were gathered quantitatively (Heikkilä et al., 2016, Zwikael and Gonen, 2007) and qualitatively (Misfeldt, 2014, Rumeser and Emsley, 2019). Many studies measured the Value of the SG with different questions, including challenge (Calderón et al., 2018) and corporation (Heikkilä et al., 2016). Desirability is another user experience measured with fun and attractiveness (Lino et al., 2015, Rumeser and Emsley, 2019). Some studies measured Usability using parameters such as immersion (Calderón et al., 2018) and clarity (Rumeser and Emsley, 2019). Usefulness is another component used to measure user experience in several studies (Lino et al., 2015, Zwikael and Gonen, 2007). A single study reported Accessibility to their SG as a user experience (Rumeser and Emsley, 2019). We can thus recognise that authors of selected publications measured player user experience with five measures: (1) usefulness, (2) usability, (3) desirability, (4) value, and (5) accessibility.

Collected user experience measures were assessed using various approaches. Studies gathered data employing Likert scale items used general statistical analysis methods: by constructing graphs, such as bar charts (Heikkilä et al., 2016, Zwikael and Gonen, 2007), and computing summary measures, such as median (Calderón et al., 2018, von Wangenheim et al., 2012). Studies that collected qualitative data used content analysis (Misfeldt, 2014, Rumeser and Emsley, 2019). A single research (Castronovo et al., 2022) reported using a modified version of an objective-specific previously developed method, a tool to assess problem-solving skills, to measure user experience. Consequently, we can identify three types of user experience assessment methods: general statistical methods, content analysis, and objective-specific methods.

5. Interpretation

This section answers the research questions based on the data analysis and synthesis. Also, we provide a conceptual framework for developing and implementing SGs in PPC education. To facilitate practical application, we have outlined a step-by-step guide, providing educators with detailed steps to integrate SGs into their courses effectively.

The first research question is: “What are the factors to consider when designing and developing SGs for PPC education?”. To address this, we summarised selected publications under the following themes: (1) Game scenario, (2) Players' roles and main activities, (3) Simulation of uncertainties, (4) Time limitations for the gameplay, (5) Strategies to make the SG ready for the implementation, (6) Assessment of in-game performance, and (7) Assessment of user experience. According to the review, defining the game scenario should consider several factors: industry, application area, and themes.

Within a single industry, there are many application areas. After selecting a particular application area, the researcher should decide on a theme to develop SGs. When defining roles for players in a SG, it is vital to select real-world professions in PPC. Although, in reality, an employee can be assigned many job-related activities during office hours, researchers should choose critical activities to simplify the game and reduce the gameplay duration. Simulation of problems that interrupt players' activities is also crucial as it enhances the realistic nature of the PPC context. Those interrupting problems should be the same problems professionals face during their jobs, and can be simulated through players, facilitators, and pre-defined programs in the SG. As far as in-game performance measures are concerned, the same industry-specific and real-world PPC performance measures can be used as in-game performance measures for PPC SGs. Also, SG must be embedded with an in-game performance recording method during the gameplay. This can be done manually with the help of players or facilitators, and SGs can be designed with a feature that can record those data. In addition to in-game performance measures, it is crucial to determine user experience measures, such as Usefulness, Usability, Desirability, Value, and Accessibility. Those measures can be used to assess the quality of the SG after the gameplay by questioning game players. Player feedback can further be used to upgrade the SG so that it better fulfils the requirements of the PPC context. Time limits of the gameplay (implementation) are another essential aspect to be carefully considered when designing SGs for the PPC context. The time duration for the whole gameplay can be determined based on the scope and complexity of the game as well as the procedure in which the experiment is conducted. Finally, we found various strategies that researchers used to prepare SGs for implementation and that can be applied in different stages within the SG development process. Those strategies can be utilised during the game development process, just before and during the gameplay implementation.

The systematic review highlights several key factors that contribute to the effectiveness of SGs in PPC education. Game scenarios rooted in real-world industry applications enhance students' engagement and practical knowledge. Role-playing in SGs mirrors actual job responsibilities, fostering critical thinking and problem-solving skills. Simulating uncertainties within SGs prepares students for unexpected challenges, improving their adaptability and resilience in PPC environments.

The second research question is: “What type of assessments can be incorporated to evaluate In-game performance and overall user experience when implementing SGs in PPC education?”. We found from the literature review that general statistical methods and industry-specific methods can be used to assess in-game performance. In addition, researchers can define a particular game score based on variables associated with the progress of the gameplay. To evaluate the overall user experience, general statistical methods can be used. In addition, objective-specific and previously published user experience assessment methods can be used. If user experiences were collected in a qualitative form, content analysis can be used to analyse those data.

5.1. A conceptual framework to support developing and implementing SGs for PPC

Based on the literature review findings, a conceptual framework is proposed to guide the development and assessment of SGs in the PPC context. This framework is shown in Figure 8.

Figure 8: A conceptual framework to guide the development and implementation of SGs for the PPC context (Source: Authors own work)

The process begins with designing and developing the SG for the PPC context based on the factors identified, as shown in Figure 7. Next, the SG should be made ready for implementation by applying appropriate strategies at different stages of the SG development process. This is an iterative process and should be continued until the SG's expectations are achieved. Next, the SG can be implemented (gameplay). After the SG implementation, gameplayers' in-game performance data and user experience data can be assessed using the previously mentioned analytical methods.

5.2. Novelty and Practical Implications

The proposed framework stands out from existing methods due to its comprehensive integration of game design elements tailored specifically for PPC education. Unlike traditional PPC teaching tools, our framework incorporates real-world scenarios, role-playing, and interactive problem-solving, which are critical for preparing students for industry challenges. This approach not only enhances engagement but also promotes active learning and retention of complex concepts.

Practically, educators can implement this framework by developing customised SGs that reflect the specific needs of their courses. For instance, using the framework, instructors can create simulations that mimic real PPC environments, allowing students to practice decision-making in a risk-free setting. This hands-on experience is invaluable for bridging the gap between classroom theory and real-world application.

5.3. Practical Implementation of the Framework

To facilitate the adoption of this framework, we outline a practical guide for educators to integrate Serious Games (SGs) into Production Planning and Control (PPC) education. These steps ensure a structured approach to effectively incorporating SGs into the curriculum.

Step 1: Needs Assessment

Educators should start by conducting a thorough needs assessment to identify the specific learning objectives for their PPC course. This includes understanding the key competencies students need to develop and determining which aspects of PPC can be enhanced through interactive learning experiences. Engage with industry stakeholders to ensure the SGs align with real-world applications.

Step 2: Selection of Appropriate SGs

Based on the needs assessment, select appropriate SGs that align with the identified learning objectives. Consider the game's content, complexity, and relevance to PPC. Evaluate existing SGs through pilot testing to ensure they meet educational goals effectively.

Step 3: Customisation and Integration

Customise the selected SGs to align with the course syllabus. Modify scenarios and roles to reflect the specific context of the PPC course. Integrate the SGs into the curriculum by scheduling dedicated sessions for gameplay, followed by debriefing sessions to discuss the outcomes and learning points.

Step 4: Preparation and Training

Prepare all necessary resources, including game materials, software, and hardware. Conduct training sessions for instructors to familiarise them with the SGs and their educational objectives. Provide students with introductory sessions to ensure they understand the gameplay mechanics and objectives.

Step 5: Implementation and Monitoring

Implement the SGs in the classroom according to the planned schedule. Monitor the gameplay sessions to ensure active participation and engagement. Collect real-time feedback from students and instructors to identify any issues or areas for improvement.

Step 6: Evaluation and Feedback

Evaluate the effectiveness of the SGs using both in-game performance metrics and user experience feedback. Conduct surveys and interviews to gather detailed feedback from students and instructors. Use this feedback to make necessary adjustments and improvements to the SGs and their implementation in future iterations.

6. Conclusion

We conclude that SGs can be used for the PPC context. To this end, we developed a conceptual framework that can guide the design, development and assessment of SGs for the PPC context. Although planning and control functions can be seen in various domains, such as healthcare, military, and agriculture, this systematic literature review was limited to manufacturing, construction, and project management. Therefore, other factors may influence designing, developing, and assessing SGs for PPC, depending on context.

Our findings reveal a paradox in PPC education: while production environments grow increasingly complex and human-centred, educational approaches have remained largely traditional and abstract. SGs address this disconnect by simulating the multifaceted nature of real-world PPC decision-making processes, including the human elements that are often overlooked in conventional teaching methods. The systematic identification of key design factors and assessment methods provides educators with practical tools to implement this innovative approach.

Despite the potential benefits, several challenges and barriers to implementing SGs in PPC education should be noted. Firstly, the high cost and resource requirements for developing high-quality SGs can be prohibitive for many educational institutions. Secondly, there may be resistance to change from traditional teaching methods to more interactive SGs, both from educators and students. Thirdly, ensuring that SGs accurately simulate real-world PPC environments while remaining engaging and educational is a complex task. Additionally, the effectiveness of SGs may vary depending on the educational context and the specific learning objectives of the PPC course. Furthermore, integrating SGs into existing curricula and aligning them with accreditation standards can pose significant challenges. These limitations should be considered when implementing SGs in PPC education.

At the beginning of the systematic literature review, we could find only a few publications related to SGs within the PPC context. Therefore, based on the factors discovered in this research, SGs can be developed for the PPC context, focusing on different industries and various objectives, such as training, behaviour change, and experiments.

Several limitations should be acknowledged. First, although planning and control functions can be seen in various domains such as healthcare, military, and agriculture, this systematic literature review was limited to manufacturing, construction, and project management. Therefore, other factors may influence the design, development, and assessment of SGs for PPC in different contexts. Second, our literature search relied primarily on the Scopus database, supplemented with snowballing techniques. While Scopus offers comprehensive coverage of relevant literature, the inclusion of additional databases might have yielded different or additional results. Future studies could expand this approach by incorporating databases such as Web of Science or IEEE Xplore to potentially capture a broader range of relevant literature. Finally, while our conceptual framework provides valuable guidance for developing and implementing SGs in PPC education, its practical application across different educational contexts and learning objectives may require adaptation. The effectiveness of SGs may vary depending on factors such as student characteristics, institutional resources, and specific learning goals.

Future research should aim to address these challenges by exploring cost-effective methods for developing SGs, such as leveraging open-source platforms and community-driven development. Additionally, studies should investigate strategies for overcoming resistance to change, including educator training and demonstrating the educational benefits of SGs. Further research is also needed to refine the balance between realism and engagement in SG design. Evaluating the long-term impact of SGs on students' learning outcomes and career preparedness in PPC fields would provide valuable insights. Moreover, expanding the application of SGs to other domains, such as healthcare and agriculture, and comparing their effectiveness across different industries could enhance our understanding of their versatility and potential. Finally, collaborative efforts between educational institutions, industry partners, and software developers can lead to more robust and widely accepted SG frameworks for PPC education.

Furthermore, future research should explore the integration of emerging technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) into serious games for PPC education. These immersive technologies offer significant potential to enhance the realism, engagement, and effectiveness of serious games. Studies comparing traditional SGs with those enhanced by immersive technologies could yield valuable insights into their relative educational effectiveness and implementation challenges in PPC contexts.

In conclusion, the integration of realistic game scenarios, role-specific activities, and simulated uncertainties within SGs significantly enhances PPC education. These elements collectively provide a comprehensive learning experience that bridges the gap between theoretical knowledge and practical application, preparing students to excel in dynamic and complex PPC environments.

This study presents a groundbreaking framework that merges Serious Games with PPC education, offering a novel approach to addressing the complexities of modern production systems. By emphasising practical application and active learning, our framework has the potential to transform PPC education, making it more relevant and effective. Future research should build on this foundation to further refine and validate the framework across different educational contexts.

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References

Abdelmegid, M. A., González, V. A., O'Sullivan, M., Walker, C. G., Poshdar, M., & Alarcón, L. F. (2023). Exploring the links between simulation modelling and construction production planning and control: a case study on the last planner system. *Production Planning & Control*, *34*(5), 459-476.

Abt, C. C. (1970), "Serious Games, New York:: Viking". *American Behavioral Scientist*. 176, available at: https://doi.org/10.2307/1953510

Agati, S. S.Hounsell, M. D. S. and Paterno, A. S. (2024), "GRAAL—modeling, prototyping and assessing a gamified responsible augmented assembly line system". *International Journal of Advanced Manufacturing Technology,* Vol. 132 No. 5-6. 2735-2751, available at: https://link.springer.com/article/10.1007/s00170-024-13460-8

Alves, S.Melzner, J. and Hollermann, S. Lean simulation game with BIM-Based progress monitoring for takt control. ANNUAL CONFERENCE OF THE

INTERNATIONAL GROUP FOR LEAN CONSTRUCTION, 2022, available at: doi.org/10.24928/2022/0132

Ammouriova, M.Bertolini, M.Castaneda, J.Juan, A. A. and Neroni, M. (2022), "A heuristic-based simulation for an education process to learn about optimization applications in logistics and transportation". *Mathematics,* Vol. 10 No. 5. 830, available at: https://doi.org/10.3390/math10050830

Andari, S. A.Cardin, O.Berruet, P. and Ardi, R. (2022), "Serious Game as Learning Media for Reconfigurable Manufacturing System: A Model Development". *IFAC-PapersOnLine,* Vol. 55 No. 10. 1675-1680., available at: https://doi.org/10.1016/j.ifacol.2022.09.638

Armenia, S.Barnabè, F.Nonino, F. and Pompei, A. (2024), "Improving project management skills by integrating a boardgame into educational paths". *International Journal of Management Education,* Vol. 22 No. 2 , available at: https://doi.org/10.1016/j.ijme.2024.100969

Arnold, S.Fujima, J. and Jantke, K. P. Storyboarding serious games for large-scale training applications. International Conference on Computer Supported Education, 2013. SCITEPRESS, 651-655., available at: DOI: 10.5220/0004415606510655

Aswathappa, K. and Bhat, K. S. 2009. Production and operations management [electronic resource] / Dr. K. Aswathappa, K. Shridhara Bhat, Mumbai [India, Himalaya Pub. House] ., ISBN : 1-282-80356-5

Ballard, G., & Howell, G. (2003). Lean project management. Building Research & Information, 31(2), 119-133.

Barbosa, M. W. and De Ávila Rodrigues, C. (2020), "Project Portfolio Management teaching: Contributions of a gamified approach". *International Journal of Management Education,* Vol. 18 No. 2, available at: https://doi.org/10.1016/j.ijme.2020.100388

Barros, M. D. O.Dantas, A. R.Veronese, G. O. and Werner, C. M. (2006), "Model-driven game development: experience and model enhancements in software project management education". *Software Process: Improvement and Practice,* Vol. 11 No. 4. 411-421, available at: https://doi.org/10.1002/spip.279

Bendul, J. (2019), "Understanding the meaning of human perception and cognitive biases for production planning and control". *IFAC-PapersOnLine,* Vol. 52 No. 13. 2201-2206, available at: https://doi.org/10.1016/j.ifacol.2019.11.532

Bendul, J. C. and Knollman, M. (2016), "The human factor in production planning and control: considering human needs in computer aided decision-support systems". *International Journal of Manufacturing Technology and Management,* Vol. 30 No. 5. 346-368, available at: https://doi.org/10.1504/IJMTM.2016.078921Borrego, M.Foster, M. J. and Froyd, J. E. (2014), "Systematic literature reviews in engineering education and other developing interdisciplinary fields". *Journal of Engineering Education,* Vol. 103 No. 1. 45-76, available at: https://doi.org/10.1002/jee.20038

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brauner, P.Philipsen, R. and Ziefle, M. Projecting efficacy and use of business simulation games in the production domain using technology acceptance models. Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future: Proceedings of the AHFE 2016 International Conference on Human Aspects of Advanced Manufacturing, July 27-31, 2016, Walt Disney World®, Florida, USA,

2016. Springer, 607-620, available at: https://link.springer.com/chapter/10.1007/978-3-319-41697-7_52
Bueno, A.Godinho Filho, M. and Frank, A. G. (2020), "Smart production planning and control in the Industry 4.0 context: A systematic literature review". *Computers & industrial engineering,* Vol. 149. 106774, available at: https://doi.org/10.1016/j.cie.2020.106774
Calderón, A. and Ruiz, M. (2015), "A systematic literature review on serious games evaluation: An application to software project management". *Computers & Education,* Vol. 87. 396-422, available at: https://doi.org/10.1016/j.compedu.2015.07.011
Calderón, A.Ruiz, M. and O'connor, R. V. (2018), "A serious game to support the ISO 21500 standard education in the context of software project management". *Computer standards & interfaces,* Vol. 60. 80-92, available at: https://doi.org/10.1016/j.csi.2018.04.012
Caserman, P. and Göbel, S. Become a scrum master: Immersive virtual reality training to learn scrum framework. Joint international conference on serious games, 2020. Springer, 34-48, available at: https://link.springer.com/chapter/10.1007/978-3-030-61814-8_3
Castronovo, F.Van Meter, P. N. and Messner, J. I. (2022), "Leveraging metacognitive prompts in construction educational games for higher educational gains". *International Journal of Construction Management,* Vol. 22 No. 1. 19-30, available at: https://doi.org/10.1080/15623599.2018.1492760
Cohen, I.Iluz, M. and Shtub, A. (2014), "A simulation-based approach in support of project management training for systems engineers". *Systems Engineering,* Vol. 17 No. 1. 26-36, available at: https://doi.org/10.1002/sys.21248
Connolly, T. M.Boyle, E. A.Macarthur, E.Hainey, T. and Boyle, J. M. (2012), "A systematic literature review of empirical evidence on computer games and serious games". *Computers & education,* Vol. 59 No. 2. 661-686, available at: https://doi.org/10.1016/j.compedu.2012.03.004
Cooper, H.Hedges, L. V. and Valentine, J. C. 2009. The handbook of research synthesis and meta-analysis 2nd edition. *The Hand. of Res. Synthesis and Meta-Analysis, 2nd Ed.*: Russell Sage Foundation, ISBN (Print) 9780871541635De Souza Costa, I.Cardoso De Oliveira Neto, G. and Rodrigues Leite, R. (2021), "How does the use of PPC tools/activities improve eco-efficiency? A systematic literature review". *Production Planning & Control,* Vol. 32 No. 7. 526-548, available at: https://doi.org/10.1080/09537287.2020.1743890
Denholm, J. A. and Stewart, I. C. A simulation for planning and executing a project. 10th European Conference on Games Based Learning: ECGBL, 2016, available at: https://www.proquest.com/openview/17b244af6409b7468c891fd995307d68/1?pq-origsite=gscholar&cbl=396495
Despeisse, M. Games and simulations in industrial engineering education: a review of the cognitive and affective learning outcomes. 2018 Winter Simulation Conference (WSC), 2018. IEEE, 4046-4057, available at: https://doi.org/10.1109/WSC.2018.8632285
Dias, J. (2017), "Teaching operations research to undergraduate management students: The role of gamification". *International Journal of Management Education,* Vol. 15 No. 1. 98-111, available at: https://doi.org/10.1016/j.ijme.2017.01.002
Drappa, A. and Ludewig, J. Simulation in software engineering training. Proceedings of the 22nd international conference on Software engineering, 2000. 199-208, available at: https://doi.org/10.1145/337180.337203

Feng, Z.González, V. A.Amor, R.Lovreglio, R. and Cabrera-Guerrero, G. (2018), "Immersive virtual reality serious games for evacuation training and research: A systematic literature review". *Computers & Education,* Vol. 127. 252-266, available at: https://doi.org/10.1016/j.compedu.2018.09.002

Feng, Z.González, V. A.Mutch, C.Amor, R. and Cabrera-Guerrero, G. (2021), "Instructional mechanisms in immersive virtual reality serious games: Earthquake emergency training for children". *Journal of Computer Assisted Learning,* Vol. 37 No. 2. 542-556, available at: https://doi.org/10.1111/jcal.12507

Galvão, T. a. B.Neto, F. M. M.Bonates, M. F. and Campos, M. T. A serious game for supporting training in risk management through project-based learning. International Conference on Virtual and Networked Organizations, Emergent Technologies, and Tools, 2011. Springer, 52-61, available at: https://link.springer.com/chapter/10.1007/978-3-642-31800-9_6

Gasca-Hurtado, G. P. and Machuca-Villegas, L. (2024), "Gamification strategy to promote social and human factors in the training of software engineers: A case study". *Computer Applications in Engineering Education*, available at: https://doi.org/10.1002/cae.22785

Gonzalez-Moret, V.Orozco, F.Senior, B.Ingle, J.Forcael, E. and Alarcon, L. (2015), "LEBSCO: Lean-Based Simulation Game for Construction Management Classrooms", available at: https://doi.org/10.1061/(ASCE)EI.1943-5541.0000243

Hart, S.Halak, B. and Sassone, V. (2022), "CIST: A Serious Game for Hardware Supply Chain". *Computers and Security,* Vol. 122, available at: https://doi.org/10.1016/j.cose.2022.102912

Hartson, R. and Pyla, P. S. 2018. *The UX book: Agile UX design for a quality user experience*, Morgan Kaufmann, available at: https://shop.elsevier.com/books/the-ux-book/hartson/978-0-12-805342-3

Heikkilä, V. T.Paasivaara, M. and Lassenius, C. Teaching university students Kanban with a collaborative board game. Proceedings of the 38th international conference on software engineering companion, 2016. 471-480, available at: https://doi.org/10.1145/2889160.2889201

Hellström, M. M.Jaccard, D. and Bonnier, K. E. (2023), "A systematic review on the use of serious games in project management education". *International Journal of Serious Games,* Vol. 10 No. 2. 3-24, available at: https://doi.org/10.17083/ijsg.v10i2.630

Herrmann, J. W. (2006). A history of production scheduling. In J. W. Herrmann (Ed.), Handbook of Production Scheduling (pp. 1-22). Springer.

Hopp, W. J., & Spearman, M. L. (2008). Factory Physics (3rd ed.). McGraw-Hill.

Hübl, A. and Fischer, G. Simulation-based business game for teaching methods in logistics and production. 2017 Winter Simulation Conference (WSC), 2017. IEEE, 4228-4239, available at: https://ieeexplore.ieee.org/abstract/document/8248129

Ilbeigi, M.Bairaktarova, D. and Ehsani, R. (2024), "A Gamified Method for Construction Engineering Education: Learning through Guided Active Exploration". *Journal of Civil Engineering Education,* Vol. 150 No. 2, available at: https://doi.org/10.1061/JCEECD.EIENG-2019

Ingason, H. T. and Eskerod, P. (2024), "Using simulations in project management education – impact on awareness and ability to navigate projects in a sustainable way". *International Journal of Managing Projects in Business,* Vol. 17 No. 2. 278-301, available at: https://doi.org/10.1108/IJMPB-08-2023-0179

Jääskä, E. and Aaltonen, K. (2022), "Teachers' experiences of using game-based learning methods in project management higher education". *Project Leadership and Society,* Vol. 3, available at: https://doi.org/10.1016/j.plas.2022.100041

Jääskä, E.Aaltonen, K. and Kujala, J. (2021), "Game-based learning in project sustainability management education". *Sustainability (Switzerland),* Vol. 13 No. 15, available at: https://www.mdpi.com/2071-1050/13/15/8204

Jan, R.Hoc, J.-M.Nasser, M.Dimopoulos, C.Van, W. W. and Pinot, G. (2010), "Design of scheduling algorithms: applications". *Behavioral operations in planning and scheduling*. 371-412, ISBN (Print): 9783642133817

Khan, K. S.Kunz, R.Kleijnen, J. and Antes, G. (2003), "Five steps to conducting a systematic review". *Journal of the royal society of medicine,* Vol. 96 No. 3. 118-121, available at: https://doi.org/10.1177/014107680309600

Khanzadi, M.Shahbazi, M. M.Arashpour, M. and Ghosh, S. (2019), "Lean design management using a gamified system". *Scientia Iranica,* Vol. 26 No. 1. 15-25, available at: https://doi.org/10.24200/sci.2018.20325

Koskela, L. (2000). An exploration towards a production theory and its application to construction. VTT Technical Research Centre of Finland

Koskela, L., & Howell, G. (2002). The underlying theory of project management is obsolete. Proceedings of the PMI Research Conference, 293-302.

Kubat, C.Öztemel, E. and Taşkın, H. (2007), "Decision support systems in production planning and control", available at: https://doi.org/10.1080/09537280600940572

Kumar, S. A. and Suresh, N. 2006. *Production And Operations Management*, New Age International (P) Limited, ISBN : 978-81-224-2425-6

Law, K. M. (2019), "Teaching project management using project-action learning (PAL) games: A case involving engineering management students in Hong Kong". *International Journal of Engineering Business Management,* Vol. 11. 1847979019828570, available at: https://doi.org/10.1177/1847979019828570

Lee, S.Nikolic, D. and Messner, J. I. (2015), "Framework of the virtual construction simulator 3 for construction planning and management education". *Journal of Computing in Civil Engineering,* Vol. 29 No. 2. 05014008, available at: https://doi.org/10.1061/(ASCE)CP.1943-5487.0000388

Leite, R. M. C.Alves, L. R. G.Cardoso, L. D. S. P. and Neto, H. M. M. (2023), "How Has Gamification in the Production Sector Been Developed in the Manufacturing and Construction Workplaces?". *Buildings,* Vol. 13 No. 10, available at: https://doi.org/10.3390/buildings13102614

Lino, J. E. N.Paludo, M. A.Binder, F. V.Reinehr, S. and Malucelli, A. Project management game 2D (PMG-2D): A serious game to assist software project managers training. 2015 IEEE Frontiers in Education Conference (FIE), 2015. IEEE, 1-8, available at: https://doi.org/10.1109/FIE.2015.7344168

Liu, M.Huang, Y. and Zhang, D. (2018), "Gamification's impact on manufacturing: Enhancing job motivation, satisfaction and operational performance with smartphone-based gamified job design". *Human Factors and Ergonomics In Manufacturing,* Vol. 28 No. 1. 38-51, available at: https://doi.org/10.1002/hfm.20723

Martín-Martín, A., Thelwall, M., Orduna-Malea, E., & Delgado López-Cózar, E. (2021). Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. *Scientometrics*, *126*(1), 871-906.

Martinez, J. G.Yeung, T.Sacks, R.Shahaf, Y. and Sharoni, L. O. (2023), "Situational Awareness in Construction Using a Serious Game". *Journal of Construction*

Engineering and Management, Vol. 149 No. 3, available at: https://doi.org/10.1061/JCEMD4.COENG-12521

Maxim, B. R.Kaur, R.Apzynski, C.Edwards, D. and Evans, E. An agile software engineering process improvement game. 2016 IEEE Frontiers in education Conference (FIE), 2016. IEEE, 1-4, available at: https://doi.org/10.1109/FIE.2016.7757682

Mcmillan, K.Flood, K. and Glaeser, R. (2017), "Virtual reality, augmented reality, mixed reality, and the marine conservation movement". *Aquatic Conservation: Marine and Freshwater Ecosystems,* Vol. 27. 162-168, available at: https://doi.org/10.1002/aqc.2820

Messi, L.De Soto, B. G.Carbonari, A. and Naticchia, B. Addressing COVID-19 Spatial Restrictions on Construction Sites Using a BIM-Based Gaming Environment. ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, 2021. IAARC Publications, 521-528, available at: https://www.researchgate.net/publication/355971114

Michael, D. R. and Chen, S. L. 2005. *Serious games: Games that educate, train, and inform*, Muska & Lipman/Premier-Trade, available at: https://dl.acm.org/doi/10.1145/3669947.3669951

Miller, G. and Núñez, V. V. The Project Win Game™: A Serious Game for Project Management Simulation. European Conference on Games Based Learning, 2022. 358-367, available at: https://www.researchgate.net/publication/364526247

Misfeldt, M. How simulation and game simultaneously frames game based learning. European Conference on Games Based Learning, 2014. Academic Conferences International Limited, 389, available at: https://www.proquest.com/openview/a9a66aa64d401a6352803d694c730352/1?pq-origsite=gscholar&cbl=396495

Moher, D.Liberati, A.Tetzlaff, J.Altman, D. G. and Prisma Group*, T. (2009), "Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement". *Annals of internal medicine,* Vol. 151 No. 4. 264-269, available at: https://doi.org/10.1136/bmj.b2535

Mongeon, P., Paul-Hus, A. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 106, 213–228 (2016). https://doi.org/10.1007/s11192-015-1765-5

Oke, A.Marfo, J. S.Kull, T.Rogers, D.Asare Marfo, A. F.Noor, M. H.Mishra, S.Mchenry, B. and Raj, S. (2024), "Investigating the effectiveness of gamification on supply chain operations knowledge and practice". *Decision Sciences Journal of Innovative Education,* Vol. 22 No. 1. 50-67, available at: https://doi.org/10.1111/dsji.12302

Oke, A. E.Aliu, J.Mwanaumo, E. M. M.Abayomi, T. and Kahanji, C. (2023), "Leveraging gamification to enhance productivity and employee engagement in the Nigerian construction industry". *Built Environment Project and Asset Management,* Vol. 13 No. 6. 813-829, available at: https://doi.org/10.1108/BEPAM-04-2023-0064

Olhager, J. and Wikner, J. (2000), "Production planning and control tools". *Production Planning & Control,* Vol. 11 No. 3. 210-222, available at: https://doi.org/10.1080/095372800232180

Potseluyko, L.Pour Rahimian, F.Dawood, N. and Elghaish, F. 2023. An Innovative BIM-Based Mixed Reality Approach for Game-Like Interactive Environments in Real-Life Industries: A Case Study of TFSBHS. *In:* POTSELUYKO, L., POUR RAHIMIAN, F., DAWOOD, N. & ELGHAISH, F. (eds.) *Platform Based Design and Immersive Technologies for Manufacturing and Assembly in Offsite*

Construction: Applying Extended Reality and Game Applications to PDfMA. Cham: Springer International Publishing, available at: https://link.springer.com/chapter/10.1007/978-3-031-32993-7_6

Potseluyko, L.Pour Rahimian, F.Dawood, N.Elghaish, F. and Hajirasouli, A. (2022), "Game-like interactive environment using BIM-based virtual reality for the timber frame self-build housing sector". *Automation in Construction,* Vol. 142. 104496, available at: https://doi.org/10.1016/j.autcon.2022.104496

Pour Rahimian, F.Seyedzadeh, S.Oliver, S.Rodriguez, S. and Dawood, N. (2020), "On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning". *Automation in Construction,* Vol. 110. 103012, available at: https://doi.org/10.1016/j.autcon.2019.103012

Rachman, A. and Ratnayake, R. C. A game-based learning system to disseminate kanban concept in engineering context: A case study from risk-based inspection project. 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2017. IEEE, 2296-2301, available at: https://doi.org/10.1109/IEEM.2017.8290301

Rissanen, M.Metso, L.Elfvengren, K. and Sinkkonen, T. Serious games for decision-making processes: a systematic literature review. Engineering Assets and Public Infrastructures in the Age of Digitalization: Proceedings of the 13th World Congress on Engineering Asset Management, 2020. Springer, 330-338, available at: https://link.springer.com/chapter/10.1007/978-3-030-48021-9_37

Rodrigues, J. D. S.Pistori, D. S.Zambon, K. L.Scarelli, A.Lima, R. M. and Carvalho, D. (2012), "Model of a game for improving integrated decisions in production management", available at: https://hdl.handle.net/1822/19184

Romagnoli, G.Galli, M.Mezzogori, D. and Reverberi, D. (2022), "A Cooperative and Competitive Serious Game for Operations and Supply Chain Management–Didactical Concept and Final Evaluation". *International Journal of Online and Biomedical Engineering,* Vol. 18 No. 15. 17-30, available at: https://dx.doi.org/10.3991/ijoe.v18i15.35089

Ruiz De La Torre Acha, A.Rio Belver, R. M.Fernandez Aguirrebeña, J. and Merlo, C. (2024), "Application of simulation and virtual reality to production learning". *Education and Training,* Vol. 66 No. 2-3. 145-165, available at: https://doi.org/10.1108/ET-02-2023-0051

Rumeser, D. and Emsley, M. (2019), "Can serious games improve project management decision making under complexity?". *Project Management Journal,* Vol. 50 No. 1. 23-39, available at: https://doi.org/10.1177/8756972818808982

Sacks, R.Esquenazi, A. and Goldin, M. (2007), "LEAPCON: Simulation of lean construction of high-rise apartment buildings". *Journal of Construction engineering and management,* Vol. 133 No. 7. 529-539, available at: https://doi.org/10.1061/(ASCE)0733-9364(2007)133:7(529)

Sailer, M.Hense, J. U.Mayr, S. K. and Mandl, H. (2017), "How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction". *Computers in human behavior,* Vol. 69. 371-380, available at: https://doi.org/10.1016/j.chb.2016.12.033

Schell, J. 2008. *The Art of Game Design: A book of lenses*, CRC press, available at: https://doi.org/10.1201/9780080919171

Sharma, S. and Trivedi, P. (2019), "Software project management training through game like simulation and virtual reality". *International Journal of Innovative Technology and Exploring Engineering,* Vol. 8 No. 10. 1090-1094, available at: https://doi.org/10.35940/ijitee.I8411.0881019

Shehab, L.Malaeb, Z. and Hamzeh, F. (2024), "Harnessing LPS Metrics for Smarter Resource Allocation and Project Control through Gamification". *Lean Construction Journal,* Vol. 2024. 1-15, available at: https://www.researchgate.net/publication/380263546

Solan, D. and Shtub, A. (2019), "The influence of competition on new product development project planning decisions". *IEEE Transactions on Engineering Management,* Vol. 68 No. 5. 1398-1405, available at: https://doi.org/10.1109/TEM.2019.2910207

Stefanidi, E.Arampatzis, D.Leonidis, A.Korozi, M.Antona, M. and Papagiannakis, G. (2020), "Magiplay: An augmented reality serious game allowing children to program intelligent environments". *Transactions on Computational Science XXXVII: Special Issue on Computer Graphics*. 144-169, available at: https://link.springer.com/chapter/10.1007/978-3-662-61983-4_9

Tagliabue, L. C.Mastrolembo Ventura, S.Teizer, J. and Ciribini, A. L. A serious game for lean construction education enabled by internet of things. Ludic, Co-design and Tools Supporting Smart Learning Ecosystems and Smart Education: Proceedings of the 5th International Conference on Smart Learning Ecosystems and Regional Development, 2020. Springer, 225-233, available at: https://iris.unibs.it/handle/11379/533360

Thomé, A. M. T.Scavarda, L. F. and Scavarda, A. J. (2016), "Conducting systematic literature review in operations management". *Production Planning & Control,* Vol. 27 No. 5. 408-420, available at: https://doi.org/10.1080/09537287.2015.1129464

Thürer, M.Cole, R.Hanna, M. D. and Protzman, C. W. (2020), "Classroom simulations for teaching production control in nonrepetitive contexts: Insights for theory and practice". *Decision Sciences Journal of Innovative Education,* Vol. 18 No. 4. 568-588, available at: https://doi.org/10.1111/dsji.12223

Tumpa, R. J.Ahmad, T.Naeni, L. M. and Kujala, J. (2024), "Computer-based games in project management education: A review". *Project Leadership and Society,* Vol. 5, available at: https://doi.org/10.1016/j.plas.2024.100130

Van Der Zee, D. A Framework for Developing Simulation-Based Serious Games for Operations Management Education. Proceedings of the Operational Research Society Simulation Workshop, 2014, available at: https://research.rug.nl/en/publications/a-framework-for-developing-simulation-based-serious-games-for-ope

Vanhoucke, M.Vereecke, A. and Gemmel, P. (2005), "The project scheduling game (PSG): simulating time/cost trade-offs in projects". *Project Management Journal,* Vol. 36 No. 1. 51-59, available at: https://doi.org/10.1177/875697280503600106

Visser, M., Van Eck, N. J., & Waltman, L. (2021). Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. *Quantitative science studies*, *2*(1), 20-41.

Von Wangenheim, C. G.Savi, R. and Borgatto, A. F. (2012), "DELIVER!–An educational game for teaching Earned Value Management in computing courses". *Information and software Technology,* Vol. 54 No. 3. 286-298, available at: https://doi.org/10.1016/j.infsof.2011.10.005

Wang, Y.Rajan, P.Sankar, C. S. and Raju, P. (2016), "Let them play: the impact of mechanics and dynamics of a serious game on student perceptions of learning engagement". *IEEE Transactions on Learning Technologies,* Vol. 10 No. 4. 514-525, available at: https://doi.org/10.1109/TLT.2016.2639019

Warmelink, H.Koivisto, J.Mayer, I.Vesa, M. and Hamari, J. (2020), "Gamification of production and logistics operations: Status quo and future directions". *Journal of Business Research,* Vol. 106. 331-340, available at: https://doi.org/10.1016/j.jbusres.2018.09.011

Wohlin, C., Kalinowski, M., Felizardo, K. R., & Mendes, E. (2022). Successful combination of database search and snowballing for identification of primary studies in systematic literature studies. *Information and Software Technology*, *147*, 106908.

Zwikael, O. and Gonen, A. (2007), "Project execution game (PEG): training towards managing unexpected events". *Journal of European Industrial Training,* Vol. 31 No. 6. 495-512, available at: https://doi.org/10.1108/03090590710772668