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DEVELOPMENT OF A SERIOUS GAME IN CONSTRUCTION LOGISTICS CONSIDERING DIGITAL AND LEAN TOOLS

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ABSTRACT

All construction projects require well-organized logistics processes to ensure progress within budget and time. However, these processes are often decentralized and inefficient, leading to waste, high costs and delays. Business games have proven effective in raising awareness of the importance of construction logistics and disseminating optimization concepts.

Based on a systematic literature review of digital tools in construction logistics and a user-oriented approach, a serious game was developed in an iterative process to highlight the benefits of these tools and the relevance of logistics. Designed for 10–17 participants over 2.5 hours, the game introduces principles like Pull, Kanban, Just-in-Time, and the Supermarket concept for pre-positioned storage near construction sites. The game also incorporates a digital delivery bill, enabling continuous tracking via QR codes and partially automated evaluations of delivery times and progress. To evaluate the developed serious game, feedback was collected from the participants through questionnaires and expert interviews.

This interactive approach demonstrates the value of digital tools and fosters understanding of efficient construction logistics practices. The target group consists of students and professionals, who should understand the effects of the use of lean construction and digital tools in the field of construction logistics.

KEYWORDS

Simulation, logistics, lean construction, digital lean, action learning.

INTRODUCTION

Construction logistics is crucial for the successful accomplishment of modern construction projects. It comprises the planning, management and control of all logistical processes on a construction site and contributes significantly to efficiency, productivity and safety (Tetik et al., 2019). A centralized organization of construction logistics enables the trades to concentrate on their core tasks while logistical processes are professionally coordinated. This reduces complexity for those involved and optimizes the use of limited resources such as storage space and transport routes. Structured construction logistics increases efficiency through early and

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holistic planning, avoids bottlenecks and minimizes idle times. It is particularly useful for projects with limited storage and working space, such as in urban areas (Bortolini et al., 2019). Construction logistics can be improved with the help of lean principles (Leifgen & Kujajewski, 2018). Tidy construction sites contribute to compliance with safety and legal standards, which increases occupational safety and labor efficiency by reducing the amount of resources standing around unnecessarily. In addition, specially allocated and smaller warehouse logistics areas encourage stakeholders to apply the pull principle and focus only on essential resources (Le et al., 2024).

In addition, there is often a lack of high-quality, standardized data to facilitate precise planning and documentation in projects without a centralized construction logistics organization. This makes it difficult to clarify responsibilities and track processes.

The central use of digital tools offers great potential for overcoming these obstacles. Real-time data increases transparency and facilitates fast decision-making. Technologies such as digital delivery tickets or QR-codes simplify the tracking of material flows and enable process automation (Liu & Pan, 2024). The continuous collection of data helps to identify weak points and optimize processes. The combination of lean principles with digital tools in the construction logistics sector therefore offers the opportunity to handle the overall project more efficiently, while at the same time providing economic and organizational benefits for the individual stakeholders. However, the implementation of a centralized construction logistics concept poses challenges. It requires a robust digital infrastructure and acceptance of the technologies by their users. Another obstacle is the perception of costs. The initial costs for centralized construction logistics appear high, while the long-term efficiency gains are often not immediately tangible.

This simulation game offers an effective way of vividly conveying the benefits of well-organized and digitally supported construction logistics (Bergström et al., 2020). The simulation game simulates complex interrelationships and challenges of construction logistics in a controlled environment. Participants experience various scenarios and immediately recognize the effects of their decisions (Klabbers, 2009). The integration of digital and lean-based approaches not only illustrates the practical benefits of modern technologies but also sharpens understanding of their application (Bhatnagar et al., 2023). It also creates an understanding of the initial costs, which are amortised through the reduced logistics effort and the tidy construction site over the course of the project. This method promotes the transfer of knowledge and facilitates the transfer into practice. This paper examines the development of a serious game that addresses the challenges and potentials of construction logistics and demonstrates the application of digital tools and lean principles. The aim is to create a deeper understanding of the importance of well-organized and digitally supported construction logistics and to sustainably increase the acceptance of such concepts.

Section 2 deals with existing serious games dealing with construction logistics, digitization in construction or a combination of those two aspects. The process of creating the serious game including the result is described in Section 3. In Section 4 the findings are discussed, followed by a summary and an outlook in Section 5.

RESEARCH GAP AND OBJECTIVE

A comprehensive literature search was conducted using a combination of keywords to identify serious games that address either construction logistics, the subject of digitalization or a combination of these two areas. In addition to a structured literature review, publications on serious games were researched at institutions (GLCI, LCI and IGLC) that deal with the dissemination of knowledge and experience in the field of Lean Construction (LC) using serious games. A comparison of seven relevant publications is presented below, outlining their objectives and methodologies.

Heyl (2015) developed a two-round game simulating underground construction logistics, demonstrating Lean improvements in productivity. Bergström et al. (2020) introduced a board game within the MIMIC project, focusing on reducing traffic congestion from uncoordinated material deliveries. Van den Berg et al. (2017) designed *Tower of Infinity,* a solo board game teaching Supply Chain Management through Lego skyscraper construction.

Teizer & Melzner (2019) created the BIM-IoT-LC Serious Game, where teams build Lego airplanes, utilizing real-time IoT data to enhance efficiency. Alves et al. (2022) extended a Lean construction game with BIM and QR codes for semi-automated progress tracking in hotel construction. Cisterna et al. (2021) developed a cloud-based game for remote learning of Lean principles and the Last Planner System. Jacobsen et al. (2021) introduced a VR business game where participants complete site-specific tasks while applying the 5S methodology. Table 1 summarizes the serious games analyzed with their focus, the teaching objective and methodology.

Table 1: Overview of analyzed serious games

Author	Focus	Teaching objective	Teaching methodology
Heyl (2015)	Construction logistics	Lean principles	Analogue
Bergstroem et al. (2020)	Construction logistics	Basics of logistics and communication	Analogue
Van den Berg et al. (2017)	Construction logistics / SCM	Basics of SCM	Analogue
Teizer & Melzner (2019)	Construction controlling	BIM, IoT and LC	Analogue using digital elements
Alves et al. (2022)	Construction controlling	Takt planning and Takt control, BIM	Analogue using digital elements
Cisterna et al. (2021)	Construction work	Lean principles, Last Planner	Cloud-based platform
Jacobsen et al. (2021)	Construction work	5S	Virtual reality environment

Based on the conducted literature review, a serious game focusing on construction logistics and taking into account the use as well as added value of digital tools has not yet been developed. This research gap provides the basis for the serious game developed. The game's objective is to facilitate experiential learning of lean logistics principles and the potential of digital tools for improving construction supply processes. The intended learning outcomes include a deeper understanding of process transparency, the importance of real-time information exchange, and the role of structured communication in managing on-site logistics challenges.

CREATING A SERIOUS GAME

METHODOLOGY FOR THE DEVELOPMENT

The objective of the serious game was to enable participants to collaboratively construct a one-story Lego Duplo building within a predefined time frame, while complying with specific

construction guidelines. The game has been designed to simulate typical construction logistics challenges, such as the coordination of material deliveries from different storage areas and the handling of process uncertainties (Haag & Jünger, 2023). In contrast to game theory approaches that focus on modeling competitive behavior between actors (Piraveenan, 2019), the game presented in this study was designed as a learning tool to foster collaboration, reflection, and knowledge exchange in construction logistics. The game was developed in three stages, following the Lean approach of striving for perfection through continuous process improvement. The development process was based on the PDCA cycle (plan, do, check, act) (Liker, 2004), which was repeated three times. In each development stage, a fundamental game concept was designed (Plan), tested with a selected group (Do), evaluated (Check), and subsequently improved (Act) (Figure 1).

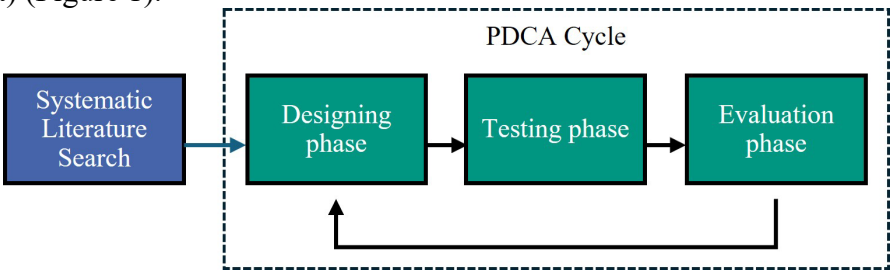

Figure 1: Game Development Process

As a first run in the Plan phase, a game concept was created based on literature research on challenges and solutions in construction logistics. Afterwards the objectives and requirements of the serious game were defined. These were adapted in each subsequent stage based on insights from the previous iteration, following Harteveld's (2011) assertion that a business game must integrate the three dimensions of reality, meaning, and play.

In the Do phase of each development stage, the business game was conducted with a participant group to verify the initially defined objectives. In the first stage, nine non-expert participants tested the game to assess its flexibility, entertainment value, and simplicity (play dimension). In the second stage, nine university-affiliated individuals evaluated the game's ability to be educational, inspiring, and motivating (meaning dimension). In the third cycle, ten construction professionals participated to assess the game's realism (reality dimension).

To collect feedback and document observations during the testing phases, online surveys, personal notes, video recordings, and audio recordings (subsequently transcribed) were used. The results were analyzed and discussed to inform the subsequent development stage, with selected improvements implemented in the Act phase. Additionally, expert interviews were conducted in the first development stage to validate the construction logistics challenges presented in the game, ensuring its practical relevance. During the Act phase, specific improvements were implemented. The concept delineated in this paper corresponds to the status of the third and final version of the game.

Structure of the Game

The developed simulation game is comprised of three rounds, each of which is divided into three phases: introduction, gameplay, and reflection (Hitzler & Schwägele, 2011). The total game duration is two hours and thirty minutes. The introduction phase provides an overview of the subsequent gameplay phase. In the initial round, participants are introduced to the fundamentals and objectives of the game. In subsequent rounds, theoretical concepts related to the applied methods and tools are explained. The gameplay phase, also referred to as the execution or action phase, actively engages participants in the business game. This phase is of pivotal importance, as learning occurs through the application of the presented theories (Thiemann, 2020). After the gameplay phase, the reflection phase is conducted, during which

participants engage in discussions and analyses of their experiences. Insights gained during the game are reviewed to reinforce learning and improve understanding. (Meßner et al., 2018, p. 15). Figure 2 gives an overview of the game process.

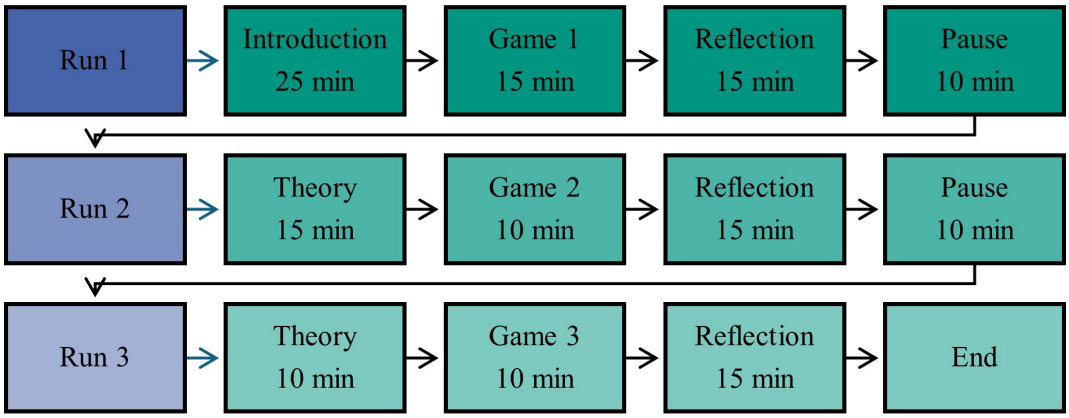

Figure 2: Structure of the Game Process

The objective of the game is for the participants to construct one-story Lego Duplo building (see Figure 3) within the assigned time frame, while adhering to the provided guidelines. The materials necessary for this project are transported to the construction site by suppliers from a total of three storage areas in the first game round and one storage area in the second and third game rounds. These materials must then be processed or assembled into a building by a skilled worker on the construction site. In addition to the roles of skilled worker and supplier, there are also the roles of game manager, site manager, foreman, warehouse workers, safety officer, and crane operator. The serious game requires at least ten participants and can be expanded to a maximum of 17 people. The roles and their task are described in Table 2.

Table 2: Role description

Role	Description	Max. Amount
Game manager	Explaining and checking the rules and the structure of the game.	1
Site manager	Manage the construction site: Check construction progress and cost status; check quality, records delivery notes, checks compliance with the rules on the construction site	2
Foreman	Check, sign and collect deliveries/delivery notes and pass on to site management	1
Warehouse workers	Load vehicles with deliveries according to delivery notes	6
Safety officer	Observes volume, stress level and supports game management	1
Crane operator	Unloads incoming deliveries on behalf of the foreman	1
Skilled Worker	Construction of the house according to plan	2
Supplier	Transports deliveries from the warehouse to the construction site and documents the delivery process analogue (rounds 1 and 2) or digital (round 3)	3

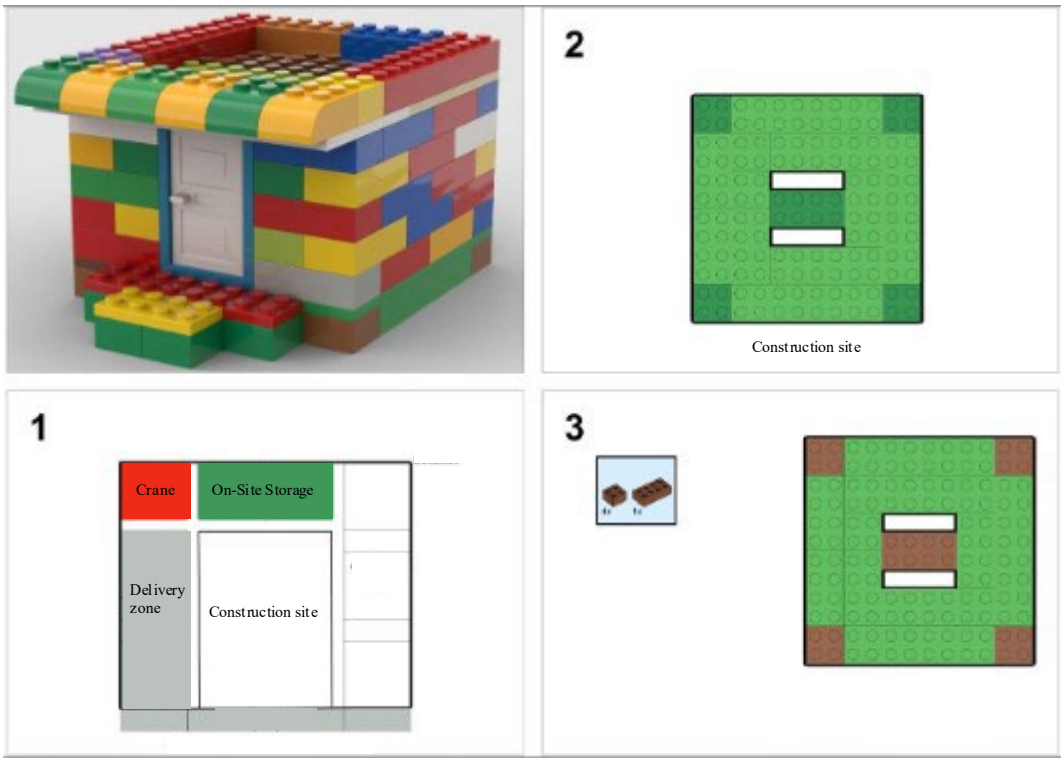

Figure 3: Building model to be constructed and excerpt of the construction plan

First round

In the initial round, the game adheres to a predetermined loading sequence, with trucks arriving at the construction site within specified time constraints. The management of material logistics is governed by stringent regulations: Warehouse operators and cranes are permitted to maneuver a limited number of units, the transfer of materials necessitates the presentation of delivery bills, and the storage of units is restricted to designated areas. The active game introduces the fundamental logistical challenges such as constrained transport capacities, documentation requirements, and spatial limitations. These challenges are mitigated in subsequent rounds through the implementation of lean construction methods and tools.

Second round

In the subsequent phase, a combination of Lean methods and tools is employed. The construction logistics process commences at a supermarket (Motzko et al., 2019), which is assumed to have been supplied by material vendors beforehand. From this point, external service providers are tasked with the preparation of the necessary construction materials and their subsequent loading onto trucks. The implementation of the pull system is achieved by the foreman, who dispatches the trucks. The Kanban method is then employed by warehouse workers to load the trucks, ensuring that only one truck at a time enters the loading area. This approach optimizes the supply chain, preventing unnecessary waiting times both at the warehouse and on-site. Since there is only one warehouse in this round, all warehouse workers operate within the same space. Materials are pre-sorted according to the construction plans and stored in the correct delivery sequence, simulating precise order planning that enables just-in-time delivery.

Third round

In the third game round, the approach of a digital delivery note is implemented to eliminating the necessity of analogue tracking of the deliveries and handing out delivery notes. Each participant is issued with an ID card that incorporates a QR code, and all deliveries are labelled

with package numbers and QR codes. Additionally, a construction site sign with a QR code is introduced for site identification. Suppliers utilize smartphones equipped with the "Scan-IT to Office" application to track deliveries in real time by scanning QR codes at four key process stages, ensuring that delivery times and responsible personnel are automatically recorded. A centralized dashboard displays the status of all deliveries and allows the suppliers, foremen and site managers to compare the actual and expected delivery status. The system is designed to facilitate the just-in-time delivery process, with material orders being pre-sorted and loading following a predetermined sequence. The automated tracking of deliveries enables an estimation of construction progress and costs, displayed as a pie chart. This demonstrates the benefits of digital delivery tracking in construction logistics.

EVALUATION

The evaluation of the developed simulation game was conducted through participant surveys using a 1-5 Likert scale and open-ended questions. A total of 19 responses from the second (9) and third (10) development stages were considered. Additionally, three expert interviews were used to assess the practical applicability of the implemented methods.

The participants had limited to no prior experience with digital tools in the construction logistics, especially digital delivery notes. Throughout the simulation, the participants experienced firsthand the added value of well-organized, digitized logistics processes, particularly which analyses are possible with a digital approach. This shift in perspective is reflected in the survey results and supports the educational impact of the game. The survey results indicate an improvement in the understanding of digital and analogue construction logistics concepts improved across the development stages. While participants in the second stage rated their comprehension at 3.6 out of 5.0, this value increased to 4.8 in the third stage. Similarly, the perceived "AHA effect" rose from 3.3 to 3.9. Although motivation for further engagement with the topic was not empirically measured, feedback and expert interviews suggest that the simulation game had an inspiring effect.

Regarding reality, the game was rated 4.0 (second test group) and 3.9 (third test group), with the latter being particularly significant as it consisted of professionals from the construction industry. The intuitive applicability of analog methods was deemed satisfactory, whereas digital tools were optimized in the third stage through the introduction of a new application and improved participant training. The findings indicate that digital functions were quickly learned.

The game mechanics were deliberately kept simple to prevent participant overload and ensure focus on the intended learning objectives. By reducing the complexity of the construction process and supply chains, attention was directed toward the advantages of new logistical concepts. Participants rated their enjoyment of the simulation at 4.3 out of 5.0, which is considered crucial for sustained engagement with the subject matter. Additionally, the game proved to be flexible, accommodating 10 to 17 participants, which facilitated seamless organization.

The evaluation confirms that the defined goals and requirements of the simulation game were met. Across three development stages, the concepts were tested and refined, while expert interviews provided a practice-oriented validation of the challenges and solutions depicted in the field of construction logistics.

CONCLUSION AND OUTLOOK

This study has laid the groundwork for understanding construction logistics by defining the term and identifying typical challenges in the field. The game was iteratively developed and tested with three groups, ensuring it met all defined goals and requirements. While the developed serious game effectively demonstrates the benefits of digital tools in construction

logistics, it should be seen as a foundation for continuous improvement following the Lean principle. Future development steps should aim to enhance the game's realism, as participants rated its realism at 3.9 out of 5. This could involve spatially separating storage areas to mimic real-world conditions. Additionally, further testing with larger participant groups and adjustments to role distributions are necessary to ensure the game's applicability with the maximum number of participants. The complexity of tasks for warehouse staff, introduced in the third development stage, should be addressed to reduce errors in delivery processing. Exploring additional Lean methods could improve delivery quality.

The use of a custom-developed digital delivery note optimizes construction time and processes, showcasing the value of real-time digital information. Currently, delivery status changes are tracked via QR code scans and displayed in a secondary app. Future developments should integrate immediate scan feedback into a single app and investigate the feasibility of fully automated delivery tracking using RFID technology. Linking the digital delivery process to a 3D building model for visualizing construction progress, similar to the approach by Alves et al. (2022), should also be explored as an extension of the game. Furthermore, subsequent studies could benefit from examining how different participant backgrounds – such as varying levels of experience with lean and digital construction methods – influence game outcomes. This would facilitate the creation of more targeted and adaptable training formats that align more closely with the participants'' prior knowledge and professional context.

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