A Digital Simulation Game for Resource Management in Construction Projects

Yara Elenany and Vian Ahmed
Department of Industrial Engineering, American University of Sharjah, UAE

yelenany@aus.edu (corresponding author)
vahmed@aus.ed

https://doi.org/10.34190/ejel.22.10.3495

Abstract: The construction industry is on the verge of a digital transformation. Consequently, the gap widens between industry demands and fresh graduate capabilities. Therefore, there is a pressing need for a paradigm shift in the teaching approach for construction management education. To meet both industry demands and student expectations, Game-Based Learning (GBL) can substantially enhance both technical and transferable skills for digital-native students who struggle with traditional teaching methods. Although the body of knowledge recognizes GBL in general, their utilization remains limited in construction management. Moreover, there is little discussion on the design process of educational games. To address these gaps, this study adopted a unique approach to educational game design by developing a time-management strategy game about resource management in construction projects with unpredictable events. This paper presents the game design process and evaluation results of a single-player digital game called '*Always Under Stress'* developed using the Godot game engine. The goal of the game is to introduce resource management in construction projects and its associated challenges. The design and development steps, game engine, and workflow are discussed in-depth in relation to the learning objectives. In addition, this study explains how elements of randomness in educational game design can be used to challenge students' planning and adaptability skills. Various stakeholders (n = 31), comprising of students, professors, and industry professionals, were invited to evaluate the game across six dimensions of educational game design. Results revealed positive reception towards the developed prototype regarding educational value and critical comments regarding user experience and onboarding for beginners. The findings of this study provide invaluable guidelines, considerations and lessons learned for prospective educational game designers and researchers.

Keywords: Game-Based learning, Digital simulation game, Construction management, Resource management, Higher education, Experiential learning

1. Introduction

The construction management field is witnessing a digital transformation. In today's fast-paced digital age, there are three key industry demands for construction managers: strong theoretical understanding, adept technical skills, and transferable soft skills. These demands are compounded by the increasing difficulty of continuing professional development after employment due to the intensive work demands of the industry (Wall and Ahmed, 2008). As a result, the gap widens between industry demands and fresh graduate capabilities (Castronovo et al., 2022). In line with changing industry demands, students place more importance on the development of transferable skills and the effective use of virtual learning tools, which they considered more practical and useful for future job prospects (Ojiako et al., 2011). Consequently, the limitations of traditional teaching methods have gained considerable attention and scrutiny in recent years to ascertain the necessary changes for bridging the gap between CM education and industry demands (Pereira and Thom, 2022). Hence, there is a pressing need for a paradigm shift in the teaching approach for CM education.

In the past two decades, research in experiential game-based learning has risen in popularity to address those limitations. Game-Based Learning (GBL) refers to a pedagogical approach using a serious game or simulation model that emulates a system or process to better recognise its underlying principles and mechanisms (Kriz, 2017). Serious games vary in complexity and realism, and they have supported educators, policymakers, and researchers for several decades (Kriz, 2017). This approach is especially important for seizing the attention of the *digital natives* who were raised in the digital age (Lee, Samad and Miang Goh, 2020). Thus, this study argues that GBL offers a highly compatible method of experiential learning in the classroom for CM education. The aim of this paper is to present the design process and evaluation of a digital simulation game called *Always Under Stress*. A relatively new software called the *Godot* game engine was chosen to develop the game, and it is explained in great detail in this paper. The findings of this study provide invaluable guidelines for prospective educational game designers and researchers.

Cite this article: Elenany, Y. and Ahmed, V. 2024. "A Digital Simulation Game for Resource Management in Construction Projects", *Electronic Journal of e-Learning*, 22(10), pp 01-18, https://doi.org/10.34190/ejel.22.10.3495

2. Simulation Games for Construction Management Education

The advantages of simulation games were discussed extensively in the literature. They provide a risk-free environment for experimentation (Dib and Adamo-Villani, 2014; Miettinen et al., 2016). Moreover, they promote experiential learning by allowing learners to engage with the subject matter directly (Oo and Lim, 2016). Reflection serves a major role in experiential learning, and digital games offer immediate, real-time feedback for learners (Miettinen et al., 2016; Perini et al., 2018). Hence, this study argues that construction management education can greatly benefit from adopting this strategy as a complementary learning tool.

Previous digital educational games in this field were mostly singleplayer experiences. In Dib and Adamo-Villani (2014), the player was a sustainability consultant who helped designers improve their buildings' environmental and economic performance. In Miettinen et al. (2016), the player was a project manager in charge of labor and change order management. In Perini et al. (2018), the player was a sustainability manager evaluating the environmental performance of a virtual company. In Kandi et al. (2020), the player was an engineer identifying design errors by walking around a virtual building. In Castronovo et al. (2022), the player was responsible for building a structure from start to finish under certain constraints. In all studies, the common thread was the kind of experience they offered learners: Linear, narrative-driven gameplay. For a breakdown of the general design parameters in digital games, ses Table 1. Overall, GBL was met with positive reception as a complementary learning tool across all prior studies. Thus, further exploration in this research field is encouraged to build upon these findings.

Table 1: Design parameters of Digital Games, adapted from (Elenany and Ahmed, 2023)

Design parameter	Description
Learning Objectives	Introduction to technical skills, problem-solving, decision-making
Number of Players	1-2 players per game
Duration per level	Less than 1 hour
Strengths of Medium	Visual, interactive, adaptive, information-intensive
Limitations of Medium	Requires coding knowledge, visual-audio assets

To expand on prior efforts in this field, three new aspects of GBL are explored in this study. The first aspect is diversity in educational game design. Currently, most games relied on linear, narrative-driven gameplay with an immersion focus. This type of gameplay does not encourage replay, and students may not absorb all the information from one playthrough. On the other hand, strategy games are inherently repetitive and iterative, revisiting a concept multiple times in different variations to fully explore its boundaries and applications. One subgenre of strategy games is the time-management simulation game, which relies on strategic planning and quick decision-making to achieve the game objectives. Thus, it can be a suitable genre for simulating construction management scenarios.

Elements of randomness can emulate the risky nature of construction projects, enhancing the learning experience where risk and strategy are involved. Moreover, they would discourage memorization or following a fixed strategy. Burgun (2018) defined two types of randomness in games. The author defined input randomness as a randomized piece of information determined before the player acts. Input randomness creates unpredictable events. Thus, it can provide an opportunity for players to learn from their mistakes and increase the replay value of a game. However, the author cautioned that misuse or over-reliance on input randomness can also lead to player frustration. On the other hand, he defined output randomness as a randomized piece of information determined as a result of a player decision. For example, a player rolling a die can result in any value between 1 to 6. Based on these definitions, neither form of randomness was found in previous GBL interventions.

In prior literature, the focus was on assessing students' technical skills or factual knowledge more often than their transferable skills. Transferable skills are competencies that are not subject-specific and can be applied to a wider range of activities, such as communication and decision-making (Ojiako et al., 2011). These skills are crucial for the professional development of CM students, whose future responsibilities entail managing dynamic, unique, and complex construction projects. Thus, linear gameplay would not suffice to represent the complexity of the manager's role. On the other hand, the time-management strategy genre may be more compatible with the goal of enhancing both technical and transferable skills simultaneously. To address these gaps, this study adopted a unique approach to educational game design and developed a strategy game about resource management in construction projects with unpredictable events.

3. Game Design Framework

Creating a game is both an artistic and methodical endeavor. Previous educational games found in the literature used different design methods, as there is currently no single agreed-upon approach (Fumarola, van Staalduinen and Verbraeck, 2012). There are limited studies on the design process of educational games from pre-development to validation, which greatly inhibits the dissemination of GBL in higher education. Thus, this study explains the pre-development, development and evaluation methodology for the developed game as guidelines for future game developers and researchers. Game design can be broken down into three general phases: Pre-development, development, and evaluation. The first two phases followed the Ten-Step Design Method developed by Fumarola, van Staalduinen and Verbraeck (2012) for simulation games. Lastly, the game evaluation strategy adopted the LEAGUE framework presented by Tahir and Wang (2020) as a guide to breaking down the game design into separate dimensions. This process is visualized in Figure 1. The rest of this section explains what each phase entails.

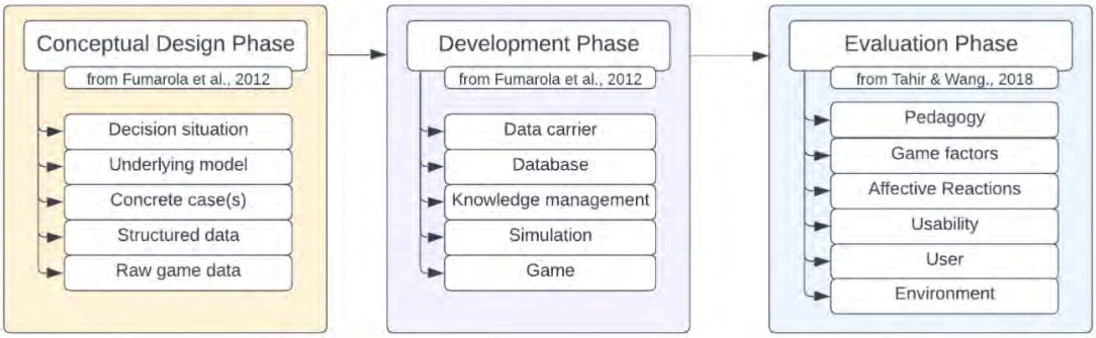

Figure 1: Visual summary of the game design process for this study

According to Fumarola, van Staalduinen and Verbraeck (2012), the goal of the conceptual design phase is to prepare the blueprint for a game concept. In modern game development, the blueprint is referred to as a Game Design Document. It is recommended to develop a concise document, as details can and will change during the course of development. This document outlines all of the necessary components for developing the game. The five steps are defined in Table 2.

Table 2: Descriptions of design steps, adapted from Fumarola, van Staalduinen and Verbraeck (2012)

Design steps	Description
Decision situation	Describe the player's role and decisions, and the game's general features.
Underlying model	Outline the rules and relationships in the game in relation to learning objectives.
Concrete case(s)	Identify the type of project(s), scope, and character(s) involved in the game.
Structured data	Collect and analyze real project data to form the basis for the game scenario(s).
Raw game data	Define in-game variables to represent the structured data.

Next, Fumarola, van Staalduinen and Verbraeck (2012) state that the development phase entails creating the simulation game. This phase involves coding, storyboarding, preparing aesthetics (i.e., audio-visual feedback), and designing the user interface. There are five recursive steps involved in development (see Table 3). In other words, external feedback from play-testers during development is a valuable tool for improving clarity and usability of the game for the target audience. Thus, this framework was adopted for this study's pre-development and development phases.

Table 3*: Descriptions of development steps, adapted from Fumarola, van Staalduinen and Verbraeck (2012)*

Development steps	Description
Data carrier	Select a platform to develop and run the simulation game.
Database	Store and organize game data in an entity relationship model.
Knowledge management	Design how information is presented to the player (i.e., user interface).
Simulation	Create a core gameplay loop and secondary systems.
Game	Test and balance game flow, adding audio-visual feedback (e.g., images, sound effects).

Next, the LEAGUE framework codified six dimensions for the evaluation of any game's design: Pedagogy, game factors, affective/cognitive reactions, usability, user, and environment (Tahir and Wang, 2020). Within each dimension were factors and metrics to measure objective data (e.g., scores and time) and subjective data (e.g., ratings and reviews). Hence, this framework forms the basis for this study's game design evaluation.

4. Selecting a Game Engine

The next preparation step is to select a game development platform, known as a game engine. This engine can then export the game file as a computer application. On itch.io, a widely recognized online marketplace for independent game developers, there are over 40 game engines listed. In the literature, there was minimal research comparing game engines. In a study by Dobroskok et al. (2020), five free game engines were reviewed for use in higher education. These engines were Unity, Unreal Engine 4, Construct 3, GameMaker Studio 2, and Godot, which corresponded to the top 5 most versatile game engines (Itch.io, 2023). Thus, these options were adapted for this study's objectives. In this study, the game engine selection consisted of three criteria: scripting flexibility, accessibility, and user experience. Table 4 summarizes the main features of each engine, followed by an explanation of the elimination process to reach the most suitable option.

Table 4: Game engine comparison

Game engine	Scripting language	Availability in the market	Engine capabilities
Godot 3.5	GDScript (primary), C# (alternative)	Free	Downloadable software, supports 2D (primary) and 3D games
Unity	C#	Free (with fees for commercial games)	Downloadable software, supports 2D/3D/AR/VR games
Unreal Engine	C++	Free (with royalty fees for commercial games)	Downloadable software, support 3D games
GameMaker Studio 2	GML and Visual scripting	Free (to learn), Paid (to publish)	Runs in browser, supports 2D games
Construct 3	JavaScript and Visual scripting	Limited free version, Subscription-based	Runs in browser, supports 2D/3D games

First, scripting flexibility determines the engine's learning curve and complexity (Dobroskok et al., 2020). There are two types of scripting methods in game engines: Visual scripting and coding. Visual scripting uses a drag-and-drop system without writing any code (Bay, 2023). Although visual scripting is beginner-friendly, coding allows for more complex design, which is desirable for a simulation game. Thus, code-based game engines (i.e., Unity, Unreal Engine 4, and Godot) were more favored for this study over visual scripting game engines (i.e., Construct 3 and GameMaker Studio 2). Moreover, the visual script-based engines offer restricted free versions, limiting the development capacity. The second consideration is engine accessibility. Unreal Engine 4 is eliminated due to its high hardware requirement and steep learning curve; moreover, this engine is more suited for 3D game development (Wilson, 2019). Lastly, the decision between Godot and Unity is decided by personal experience. After learning the basics of each engine, Godot is favored for its intuitive user interface, beginner-friendly scripting language and organized workflow. Godot also has built-in user interface tools that streamline the prototyping process, which are not available in Unity. Thus, Godot is chosen as the game engine of choice for this study.

5. Game Design Methodology

This section describes the methodology of this study, following a three-phase process: Pre-development, development, and evaluation. The first two phases are adapted from the 10-step design framework, and the evaluation phase follows the LEAGUE framework (as in Section 3).

5.1 Pre-Development Phase

The goal of the pre-development phase is to define the game's learning objectives, then represent them in a game environment. The developed game is titled, *Always Under Stress*, reflecting the pressure of a construction manager on the job. The rest of this section explains the thought process within each step.

5.1.1 Decision situation

The first step of the pre-development phase is to define the general parameters of the game. These parameters are determined from the simulation game classification framework. Table 5 summarizes the general parameters of the game developed in this study, henceforth called the developed game. The decision situation places players in charge of procuring, monitoring, and allocating resources for a construction project.

Table 5: General parameters of the developed game, titled "Always Under Stress"

Design parameter	Description
Target Audience	Undergraduate and graduate engineering students
Genre	Single-player, time and resource management, simulation, scenario-based levels
Duration	10 to 15 minutes per level
Subject	• Introduction to procurement management • Time-cost trade-off
Learning objectives	• Factual knowledge: Resources involved in construction projects • Technical skills: Time and cost management, Risk response • Transferable skills: Planning, Decision-making, Adaptability, Handling uncertainty
Game objectives	Complete the project with three objectives: • Before the deadline • Within budget • Reach a target profit margin
Decision situations	• Choose from a set of suppliers with different prices and lead times • Plan ahead to avoid delays • React to randomized risk events

The gameplay loop is the recurring decision pattern of the player towards achieving a certain goal. In this game, the player's recurring decision is to choose from a set of suppliers with different prices and lead times, then initiate construction work until all activities are completed. The core gameplay loop is illustrated in Figure 2. Similar games in the management genre include *Virtual City* (2009), *Royal Envoy* (2010), and the *Build-a-Lot* series (2007-2020).

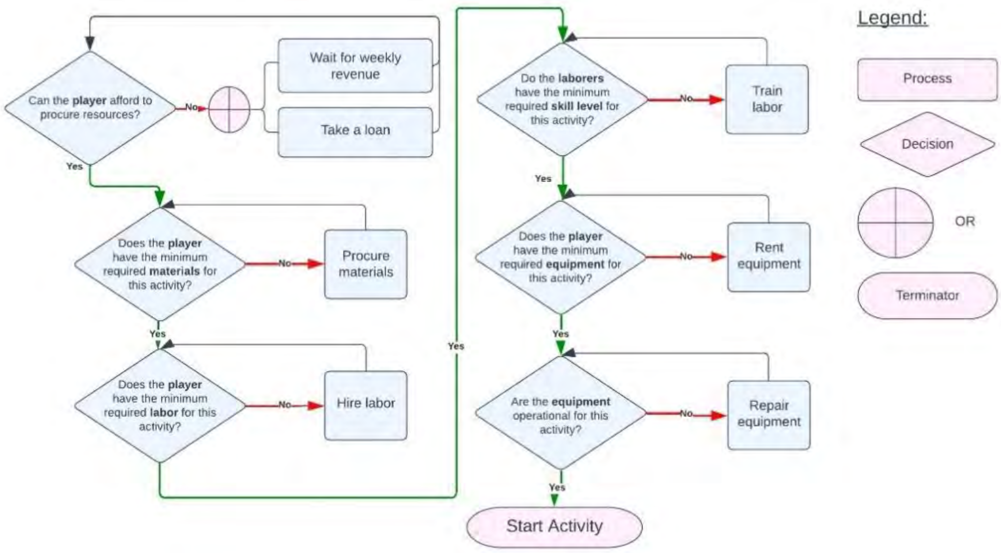

Figure 2: The core gameplay loop of the developed game (starts at the top left)

Furthermore, secondary gameplay elements are systems added to enhance the gameplay loop. The player must plan ahead to avoid delays, consider taking out a bank loan, and react to random risk events. The idea of random risk events draws inspiration from real-time strategy game, *Plague Inc.* (2021). With these parameters established and similar games available to draw inspiration from, the next step is to develop the underlying model of the simulation.

5.1.2 Underlying model

The underlying model is the second step in the pre-development phase where learning objectives are translated into game objectives. Moreover, this step is concerned with establishing the rules and relationships of the simulation game. Figure 3 illustrates the relationship between the variables in the developed game. A top-down approach is adopted for developing this relationship chart, starting from the game objectives (i.e., schedule and budget). Then, decisions are linked to each objective.

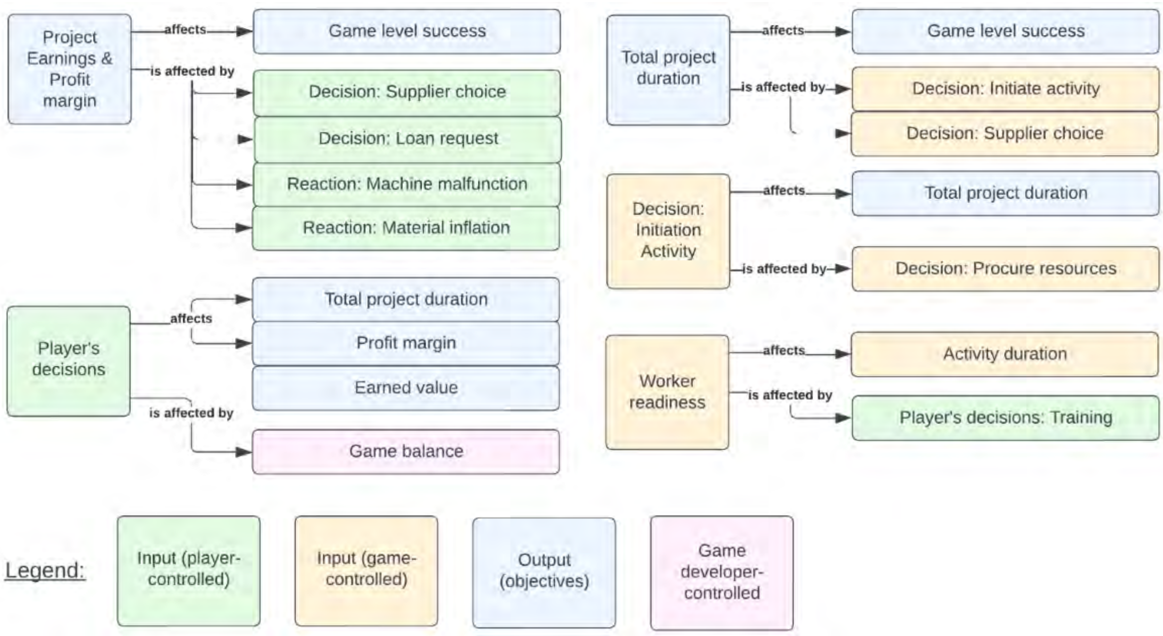

Figure 3: Illustration of the relationship chart for the developed game

By defining the relationship chart, game mechanics from established titles can be adapted. To avoid scope creep, game elements are sorted into a priority list under one of three categories: Educational, Motivational, or

Accessibility features. Narrowing down the most important variables is necessary to establish a core gameplay loop. Next, concrete cases are needed to create each level.

5.1.3 Concrete cases

The concrete cases step involves gathering data from real-life projects to define game scenarios. For this game, a simplified linear construction schedule is chosen. Second-hand information is collected from YouTube videos (see Table 6) to determine the general order of activities involved in different infrastructure projects, namely bridge and highway construction.

Table 6: Some construction-scenario videos found on YouTube

Title	Notes	URL
"How Modern Roads Are Built? Highway Construction Process"	General highway construction activities + associated resources	https://youtu.be/juWc-DpFolY?si=QH4j-TYWXfWrR6lB
"Building Construction Process | step by step | with Rebar placement"	Activities related to building foundation	https://youtu.be/vkew-1KK3Sc?si=obBNuVOLt3zRou4l
"12 Steps of Construction"	General site preparation activities + associated resources	https://youtu.be/mbwuj58UEPg?si=m6K47uhLl5p5cD1V
"Every Bridge For Every Situation, Explained By an Engineer | A World of Difference | WIRED"	Introduction to bridges, helped with finding the simplest bridge type for a beginner scenario	https://youtu.be/1bUnFjMOrPs?si=Mxs7Jpo7HAPgE-3e

The benefit of this approach is to simplify design while representing the general work involved in real construction projects. For a prototype, this method accelerates the design process without compromising validation of the game concept. With content established, the final step in the pre-development phase is to define variables in the simulation model.

5.1.4 Structured and raw game data

The structured data are the simulation components while raw game data refer to the variables being manipulated by the player. For this prototype, the project objectives are tied to two constraints: Time and Cost. Thus, the player's input is the decision to procure resources required for construction projects within time-cost limits. Four types of resources are selected for the developed game: money, materials, equipment, and labor, as described in Table 7.

Table 7: Description of in-game resources and their characteristics

Variable / Resource	Characteristics	
Money	• Small starting amount is given to the player • Earned from completing construction activities • Can be loaned from the bank with a high interest rate	
	Unique characteristics	**Shared characteristics**
Materials	• Risk of faster decay • Risk of inflated prices	• Has a time limit until it expires and cannot be used anymore • Risk of supplier delay
Equipment	• Risk of malfunction	
Labor	Each labor type has different training requirements: • Foreman, Driver (no additional training) • General workers (1 training cycle) • Tradesmen (2 training cycles) • Equipment operators (3 training cycles)	

Hence, these resources become in-game variables that the player manipulates to achieve the game objectives. Thus, the player gain contextual understanding of these terms. With all the design elements established, the development phase can begin.

5.2 Development Phase

The second phase of the game design process is the development phase. This study argues that development should focus on building a prototype to validate the game concept before committing more resources for polish. This section explains the development steps of the prototype.

5.2.1 Data carrier

The Godot game engine is the chosen data carrier (as explained in Section 4). The engine runs on GDScript, a Python-like custom coding language. It is suitable for beginner programmers due to its intuitive workflow and built-in features for full stack development (i.e., user interface and system code). To share the game with participants, the game is hosted on itch.io, and it can be accessed with a private link. Thus, participants can access the game from their own devices.

5.2.2 Database

For a simulation game, the Entity-Component-System (ECS) design pattern is implemented. This design pattern determines how game elements are created, organized, and linked to each other. A *component* is an object with a singular purpose; an *entity* is an object comprised of components; and a *system* runs code that manipulates entities and components during the course of the game. This approach is greatly complemented by Godot's *Scene-Node-Script* structure (see Figure 4).

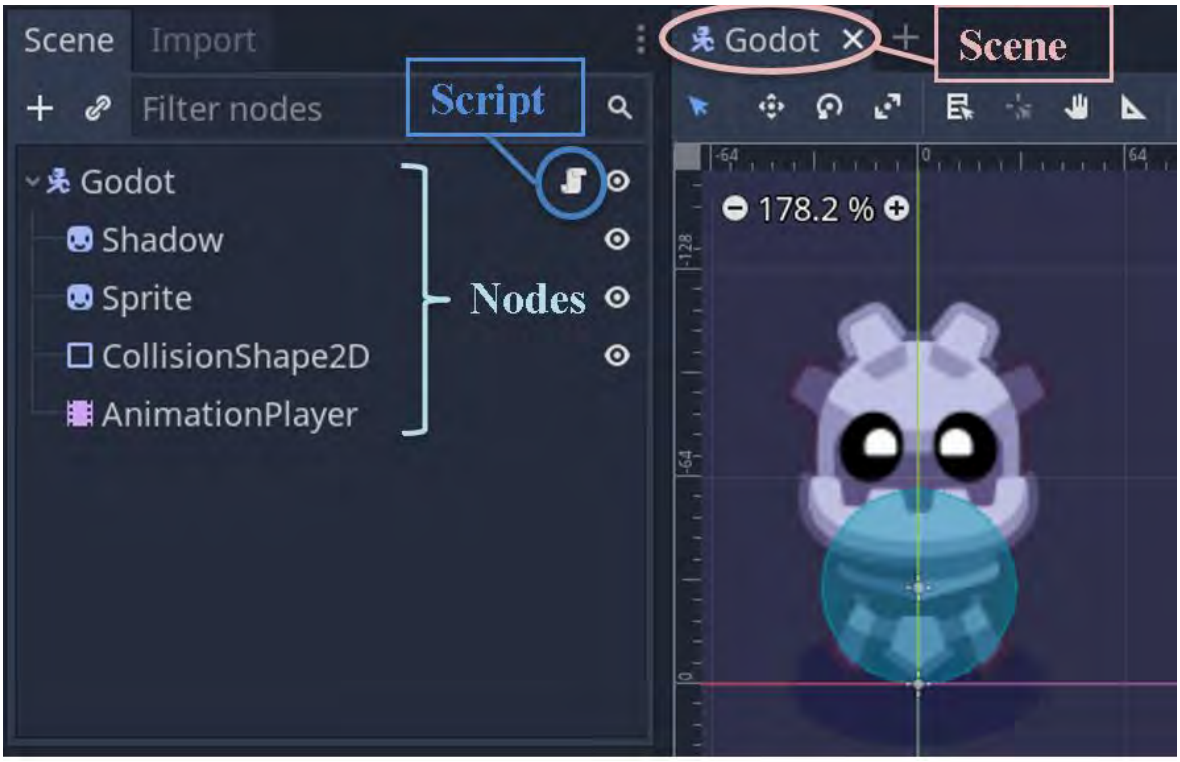

Figure 4: Object-oriented programming in Godot

In the Godot engine, every object is a *node*, and every node has a unique purpose (e.g., button, panel, character). Moreover, a *scene* is a collection of nodes organized in a parent-child hierarchy, and a *script* is attached to a node to run code. In most scenes, the scene's parent node is attached to a script that handles all children nodes' functions. This workflow allows for modular development. Each system can be edited or removed with little to no effect on other systems. The Godot engine also supports global scripts, which store information shared across all levels, such as audio-visual files and constant variables. Lastly, signals in Godot allow nodes, scenes, and scripts to react to player input. The full stack development process is described in the next step.

5.2.3 Simulation

The goal of this step is to establish the core gameplay loop. Using Godot, the following work pattern is adopted:

- **Step 1:** Construct a scene out of nodes
- **Step 2:** Write the system script that manipulates the constructed objects

- **Step 3:** Write the UI script to reflect system information to the player
- **Step 4:** Connect the scenes, systems, and UI scripts using signals.

All of the code is developed in a test environment, then duplicated to create individual levels. Thus, any changes to the code in the test scene would automatically apply to the individual levels because they share the same attached script.

5.2.4 Knowledge management

Development is inherently a recursive process, and it requires continuous testing and external feedback to improve, as seen in Figure 5. For this study, the game is treated as a standalone learning tool to identify its strengths and weaknesses outside of a classroom setting. Hence, any pre-requisite information that the player needs is presented in the game.

Figure 5: The cyclic workflow of the development step

The user interface consists of different systems to convey information to the player. It is responsible for signaling the players in the right direction when they are lost. To support this need, a short tutorial level is added to acquaint the player with the rules and controls of the game.

5.2.5 Game

To ensure balanced gameplay, debugging is needed, which refers to testing the game for unexpected or undesirable outcomes. Game elements are adjusted often to achieve a balance of fairness and challenge for players. Play-testers are encouraged at this step to gain feedback from the target audience and improve accessibility. The user interface is expected to undergo the most changes throughout the course of development.

5.3 Evaluation Phase

For this study, evaluation is carried out in three different forms: A pilot study, a quasi-experiment for students, and semi-structured interviews with other stakeholders. All participants will be referred to using unique identifiers where needed. The rest of this section describes the methodological steps involved in each step of the evaluation phase.

5.3.1 Pilot study

The goal of the pilot study is to play-test the game for accessibility, information clarity, and immersion. Thus, participants with little to no background in construction management are selected to identify areas of improvement in those aspects. A convenience sampling strategy is adopted to gather feedback quickly and efficiently. Based on the most recurring comments, changes may be needed to improve the usability. Specifically, concerns related to the core gameplay loop are prioritized while suggestions that expand on existing game mechanics are noted for future work.

5.3.2 Students' quasi-experiment

A quasi-experiment is designed to determine the educational value of the game, based on how well the game objectives translated into understanding factual and conceptual knowledge of construction management concepts. A systematic sampling strategy is used for the quasi-experiment, specifically targeting undergraduate and graduate students currently enrolled in an engineering program.

The student survey consists of six sections. The first section is about demographic information. The second to fourth sections ask about gameplay experience. The last two sections are identical knowledge tests, presented before and after playing the game. Table 8 lists the knowledge test questions from the survey. Comparing these two tests sheds light on how well the game improved students' understanding of resource management.

The questions are categorized according to Bloom's taxonomy. The first two questions check students' attentiveness to construction-related keywords found in the game. The third question assesses students ability to describe a term not directly defined in the game based on context . Specifically, words like *contract*, *supplier*, *quantity*, and *price* are expected in the answers, as these are the keywords used directly in the game. The fourth and fifth questions require attention to details as another indicator of students' active learning. The last question asks players about their risk response strategy, both hypothetically (in the pre-game test) and during the simulation (in the post-game test).

Table 8: Knowledge Test Questions

No.	Test Question	Bloom's Taxonomy Level
1	What is/are the core objective(s) of any construction project from the contractor's point of view? (Note: a contractor is a company in charge of building structures, e.g., buildings, bridge, road)	Remember (1)
2	What are the types of resources needed for any construction work?	Remember (1)
3	What is a purchase order?	Understand (2)
4	What are some criteria for choosing the best resource suppliers?	Remember (1)
5	What are some risks that could negatively impact reaching the construction project's objectives?	Remember (1)
6	How would you respond to the risks mentioned in the answer to the previous question?	Apply (3)

A point system is used to determine the extent of the students' improvement in understanding new concepts. If the response was *I don't know* or incorrect, it was awarded 0 points. If the response was partially correct, or lacked keywords mentioned in the game, then it was awarded 1 point. When a students' response was descriptive with in-game keywords or was improved from their pre-game test response, it was awarded 2 points.

5.3.3 Interviews with other stakeholders

Semi-structured interviews are conducted to collect qualitative feedback from non-student perspectives. The stakeholders include professors, industry professionals, and engineering alumni, selected using purposive sampling strategy. The shared trait among all selected participants is having prior work experience in the construction industry. The participants are invited to either play the game or watch a demonstration, then share their thoughts on the game's educational value and implementation in higher education.

6. Results and Analysis

Various stakeholders were invited to share their opinions on the developed game with respect to the six dimensions of game design evaluation: User, Affective/Cognitive Reactions, Learning, Game Factors, Usability, and Environment, as per the LEAGUE framework. The following sections discuss the strengths and weaknesses under each dimension, supported by feedback from the respondents.

6.1 Profile of the Participants

In total, 31 participants were involved in the study at different steps. The distribution of participants are illustrated in Figure 6. Moreover, Figure 7 provides more information on the distribution of participants' gender and prior game exposure. The majority of participants have played games for entertainment in the past three months, but less than half played a simulation game in particular.

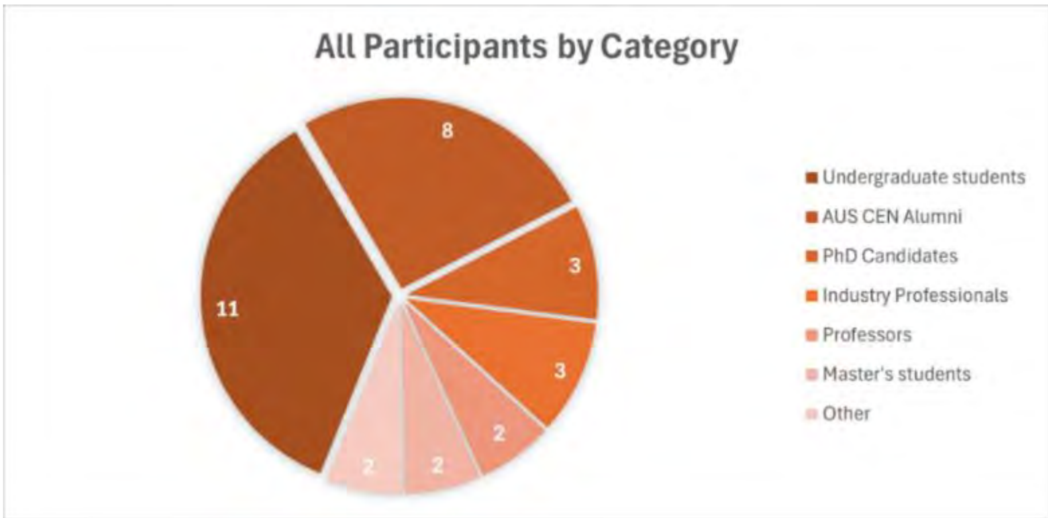

Figure 6: Distribution of all participants by category

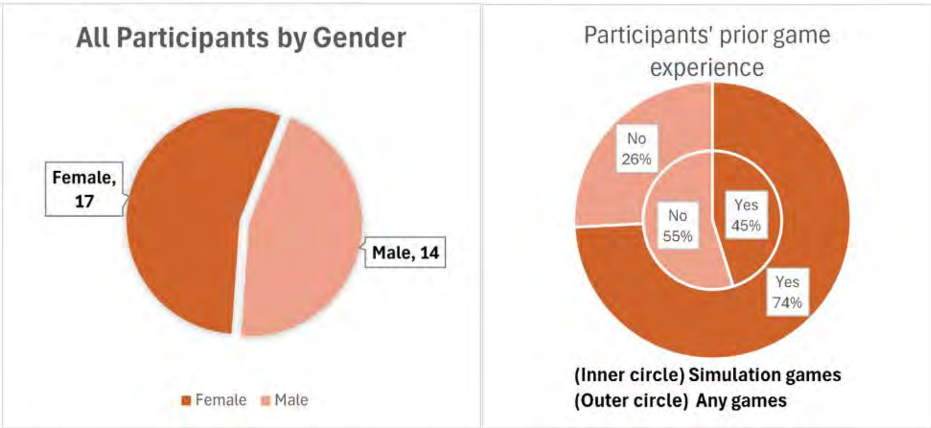

Figure 7: Demographic information. (a) Gender, (b) Prior game experience

12 students in the quasi-experiment portion of the study, whose demographic information is presented in Figure 8. The majority of students did not have prior exposure to CM concepts, either from an internship or from a university course. Therefore, this study assumes that the difference in knowledge before and after playing the game is mainly derived from the gameplay experience.

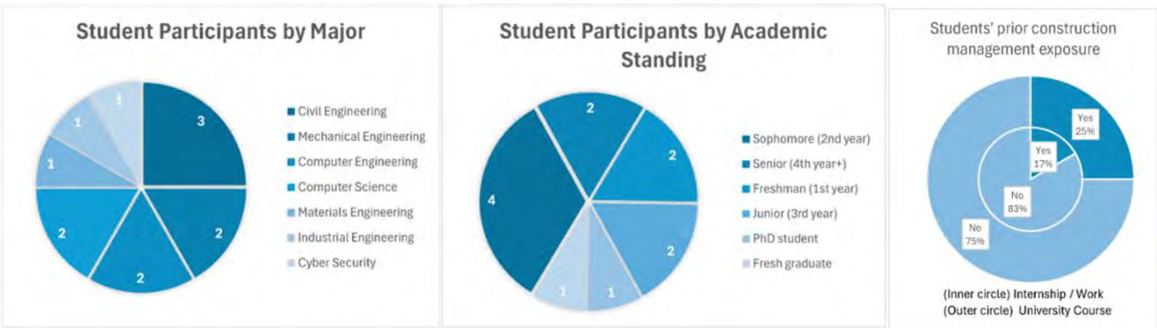

Figure 8: (left) Major, (middle) Academic standing, (right) Prior exposure to CM

The wide range of perspectives led to a well-rounded evaluation of the current prototype. The goal of this evaluation is to highlight the strengths and areas of improvement of the developed game as well as shed light on educational game design advice for future researchers.

6.2 Evaluating the User Dimension

In the LEAGUE framework, the User dimension assesses the extent to which the cognitive and psychological needs of the user are considered in the game. The intended target audience for the game is undergraduate students new to construction management. Regarding cognitive needs, the user should be gradually introduced to the game rules. Hence, a tutorial level is created to guide the player on a small scale. Second, there should be adequate visuals attached to new keywords. For the developed game, one participant said the use of unique images to represent each material, equipment, and laborer is *visually appealing* and *aids in understanding*. Regarding the psychological needs, participants may feel stressed at certain points of the game, especially players who are new to time-sensitive games. To accommodate for this, the player is able to pause or restart the level if the current run feels hopeless.

6.3 Evaluating the Affective/Cognitive Dimension

Open-ended survey questions served to gain insight into the players' gameplay behavior and experience from both cognitive (learning) and affective (feeling) lenses. These questions were shared among both students (labelled S) and interviewees (labelled I) who opted to play the game. These insights inform better game design practices in the future for simulation games that are minimally discussed in the literature.

When asked about their feelings towards the game (see Figure 9), most participants agreed that it was challenging but useful. Moreover, most players put considerable effort, though not all of them felt confident in their abilities. These reactions are expected, as the game was designed to challenge the players in an area they are unfamiliar with. In addition, this distribution of feelings indicates that the difficulty of the game did not impair the players' perception of its usefulness as a learning tool.

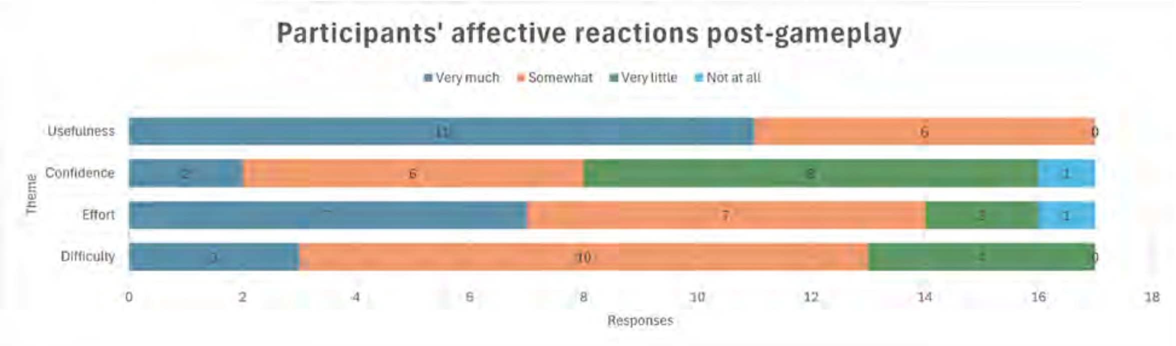

Figure 9: Affective reactions post-gameplay

When asked to describe what players liked, 9 participants praised the developed game's ability to simulate resource management of construction projects in a *fun* yet *challenging* manner suitable for undergraduate students. Specifically, one student called it a *fun brain exercise* (S8), and another said it was *both educational and enjoyable* (I2). Furthermore, 8 participants applauded the level scenarios for being realistic or reflective of a real-life experience. This realism also enhanced the immersion of the game, as one student admitted, *at some point I forgot I was playing it for reviewing it* (S6). Some students highlighted specific in-game tasks that supported this view, as follows:

> *"Even the tiniest detail of training labor or having them get injured or not having enough space on site was amazing." (S6)*

> *"There were day-to-day issues and management that surprised me to see in a game but would not have surprised me to see in real life." (S7)*

> *"I liked the random events that can occur to ruin your run, they're not intrusive enough to be annoying but just enough so it can add to the challenge. it was pretty exciting to try and work under a time limit." (S8)*

> *"included most of the details that are usually involved in construction projects, such as unexpected delays, storage space issues, etc." (I3)*

In the next section of the survey, student participants were asked about their cognitive reactions towards the game (see Figure 10). Regarding their feelings towards the time spent in the game, they were split on whether it was worth it or not. This was the only statement with the most diverse opinions. Conversely, there was a majority agreement about the game being thought-provoking, enjoyable, and aligned with its learning objectives. In addition, most students agreed that they played an active role in their learning during the game.

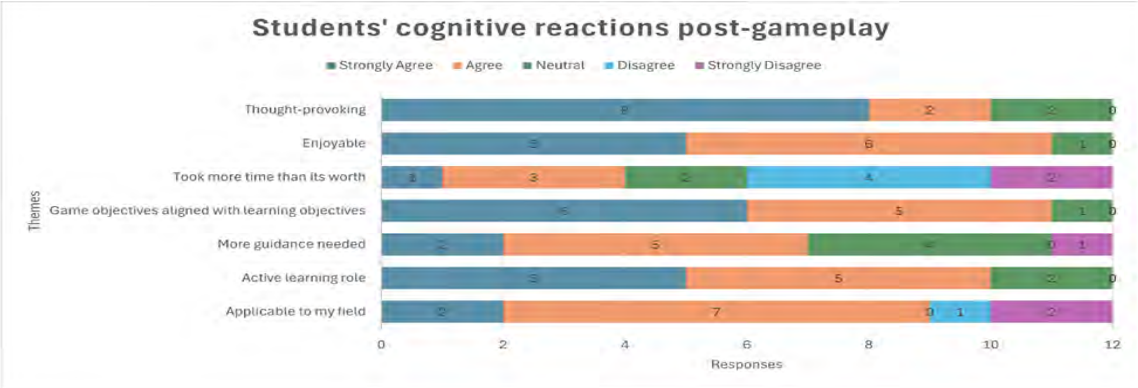

Figure 10: Students' cognitive reactions post-gameplay

Based on these results, the students' perception of the game was mostly positive and aligned with the objectives. The next section will discuss how these feelings translate into knowledge gained according to the results of the pre-game and post-game tests as well as participants' reflections.

6.4 Evaluating the Learning Dimension

The learning dimension is concerned with evaluating the educational value of the developed game. Generally, the majority of players agreed or strongly agreed with the statement of gaining a better understanding of several learning objectives, technical and transferable skills, as seen in Figure 11.

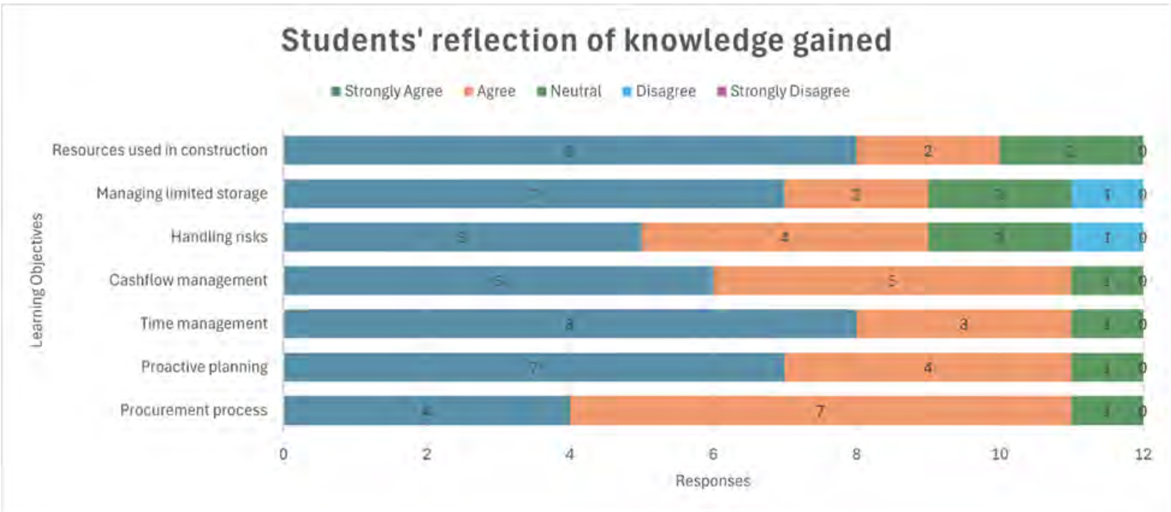

Figure 11: Students' reflection of knowledge gained

When asked to describe their most important takeaways from the gameplay experience, the participants recognized the value of *planning ahead* (S2, S6, S8, I4)*, adapting to change* (S2, S6)*, strategic thinking* (S6, S8), and *decision making* (I5). In addition, one computer engineering student (S9) found the game approachable and relevant for their career development despite construction not being their major. Regarding specific moments during the game, some participants shared their observations:

> *"now i know the importance of keeping track of time and money in a construction project and there were several factors that i didnt think of such as material getting expired or machines breaking down and need fixing." (S3)*

> *"Buying cheap material is not always the best solution." (I1)*

Furthermore, a couple of AUS alumni praised game-based learning as a novel approach that they had not encountered before. They reflected on the usefulness of the developed game as a learning tool for undergraduate students, describing their views as follows:

> *"I really like the idea of having a simulation game being introduced for undergraduate students, as it allows them to step into the shoes of a manager and make important decisions and then face the*

> *consequences of those decisions. It gives you a new perspective and prepares you for managerial roles." (I2)*
>
> *"This kind of simulation games is a very useful idea to help students understand how construction project management works and to give them a close resemblance of real-life project management experiences." (I3)*

For the knowledge test component of the survey, the student participants were given six questions. Figure 12 present the results of the pre-game and post-game tests, respectively. Overall, there was 115% improvement across all questions (from 19 to 41 total 2-point answers), mostly shifting from 1-point to 2-points, with the exception of questions 3 and 6. For question 3, three students did not change their answers, two students improved significantly (from 0 to 2 points), and one student did worse (1 to 0 points). 5 participants recognized that the role of a manager was *important* (S4, S7, S12), *difficult* (S1, S11), and even *risky* (S1). As one student wrote, *management has a major responsibility to be as focused as possible to keep track of everything for the sake of the health of the project* (S7).

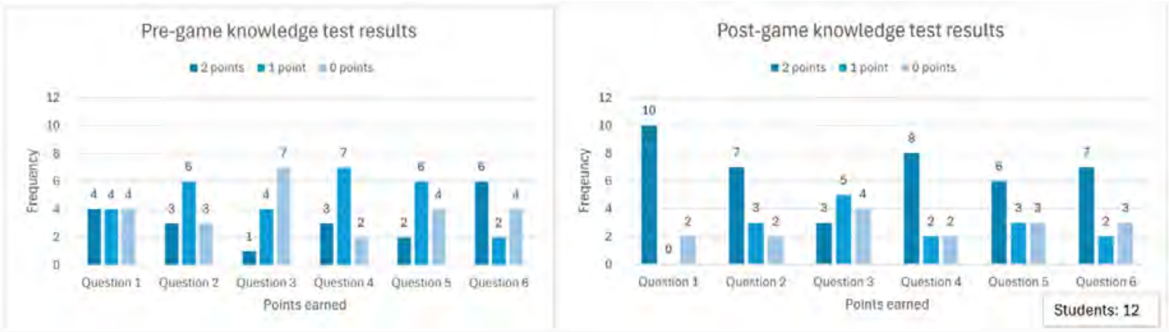

Figure 12: Pre-game (left) and post-game (right) knowledge test results

The students' recognition can be attributed to the inherent difficulty in the game. The next section will discuss the players' reactions to the game factors.

6.5 Evaluating the Game Factors Dimension

Assessing the replay value of the game was one of the goals of the study. Previous studies mostly focused on evaluating the extent of learning through playing a game once. However, this study argues that there is added value in learning gained from repetition, and there must be some variety and challenge to the gameplay to incentivize replaying the same level as a means to learn from past mistakes. Figure 13 shows how often each level was attempted. All participants attempted Level 1 while fewer continued to Level 2. Moreover, most players played each level once or twice at most, and 5 players repeated the same level 4 or more times with the highest repeat count at 10 times. This number may include restarts in the middle of the level. In the survey, the participants were invited to play for as long or as little as they wished.

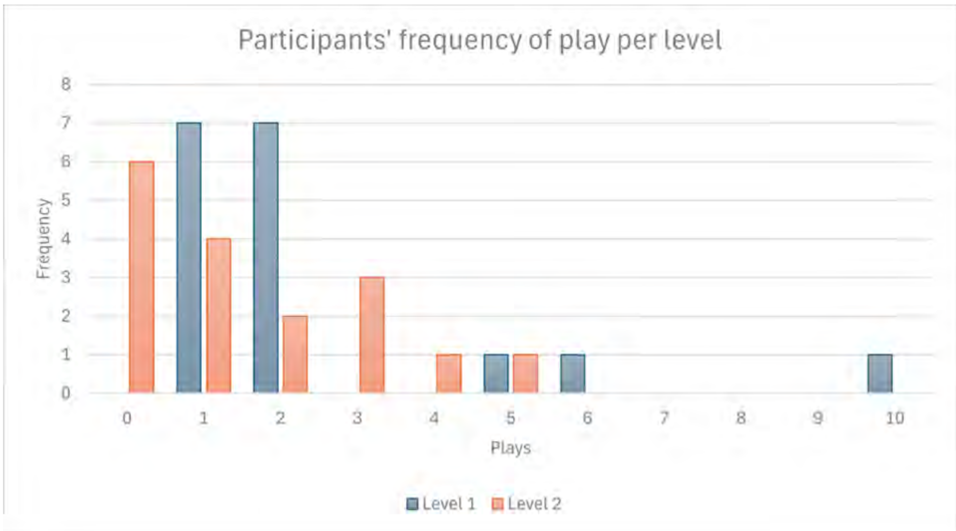

Figure 13: Frequency of play per level

Figure 14 presents the distribution of time spent in the game. 10 out of 17 players spent between 10 to 40 minutes on the game, and two people spent up to 90 minutes. Regarding gameplay, the participants rated each task based on how easy or difficult it was to execute (see Figure 15). According to these results, the core gameplay loop was considered mostly very easy or somewhat easy (e.g., starting activities, selecting suppliers) while the most difficult tasks were the secondary game mechanics (e.g., responding to risks). Monitoring and tracking tasks were also deemed mostly somewhat difficult. Thus, adding the option for an auto-tracking system in the game may be helpful for players. When asked about personal factors that may influence their game performance, the players were given several options to consider (see Figure 16). Most respondents stated that they were not familiar with the subject and yet found it interesting and pleasant. Most notably, the game was not considered easy or luck-based by at least half of the participants. These results suggest that those players perceived their success or failure as a consequence of their own decisions rather than a system-influenced outcome.

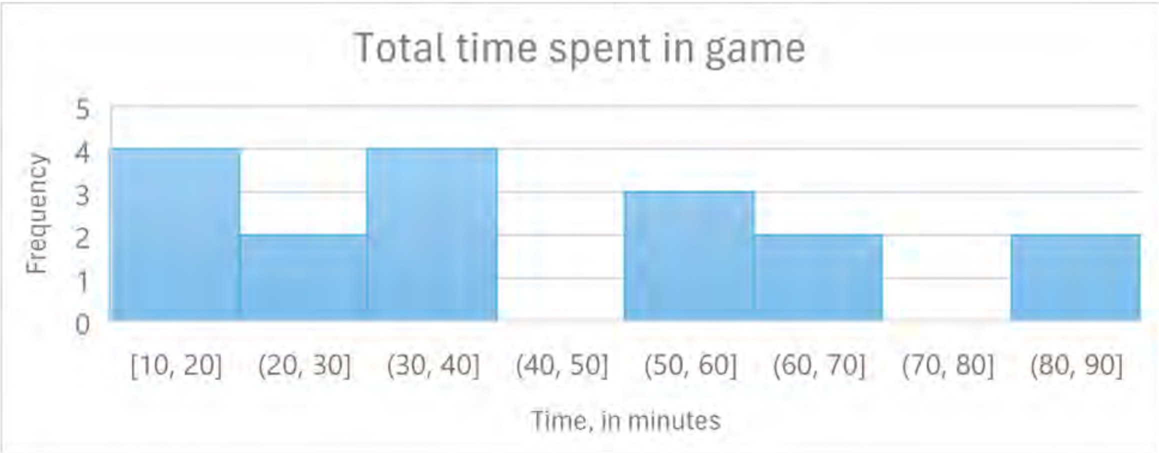

Figure 14: Total time spent in game

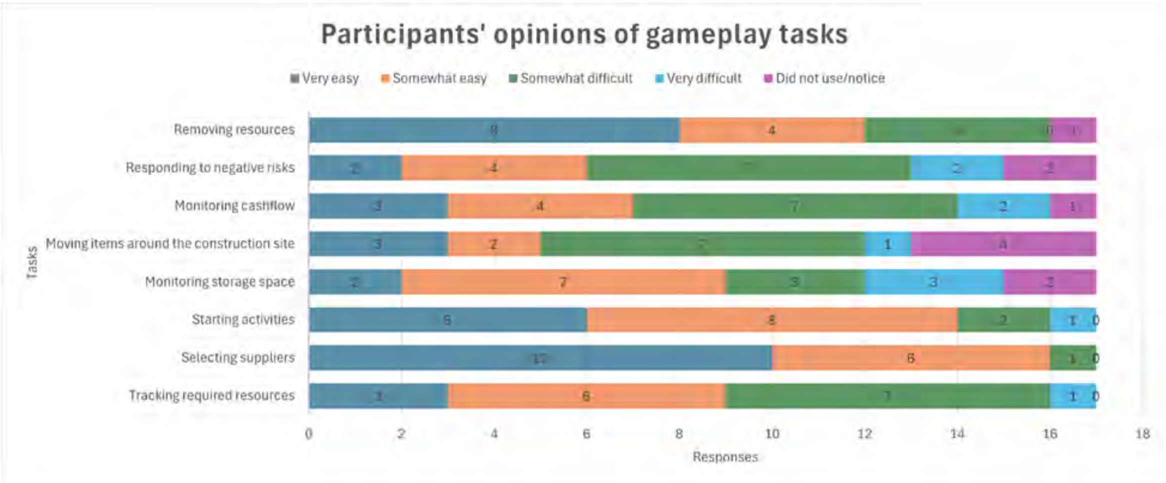

Figure 15: Participants' opinions of gameplay tasks

Time management was one of the intended challenges in the game. 7 players (S1, S3, S5, S7, S9, I1, I2) mentioned struggling with the time scale in the game. This issue impacted the core gameplay loop, as it conflicted with the goal of careful decision-making. To address this concern, a few suggestions were provided. One alumnus (I1) recommended presenting time in the game in terms of minutes and seconds, rather than days and weeks. Three participants (S6, S12, I2) offered a different solution: *Customizable pacing.* This option would allow the player to slow down or speed up time to fit their own pace. This suggestion is commonly found in contemporary simulation games and was noted down for future development.

Most students mentioned focusing on the time objective over the cost objectives. In fact, 66% of students described actively changing their strategy to be within schedule. Some students planned each task at a time (S6,S7,S9) or prioritized the cheapest supplier (S8), leading to delays and missing the schedule objective. Upon repeating the level, they realized the importance of planning ahead and adopted that strategy moving forward, as described in their own words:

> *"after noticing that I am late on schedule I decided to risk it by managing tasks and ordering resources beforehand while the previous task is being done, which was kind of confusing at first, but saved alot of time eventually" (S6)*

> *"eventually i started hovering over the future steps and ordering materials in bulk so i have them on hand even if they were not needed immediately. i had to think of future plans to cut down on lead time" (S7)*

> *"the more I played and understood the mechanics, I changed my strategy to thinking ahead and making using of resources efficiently" (S9)*

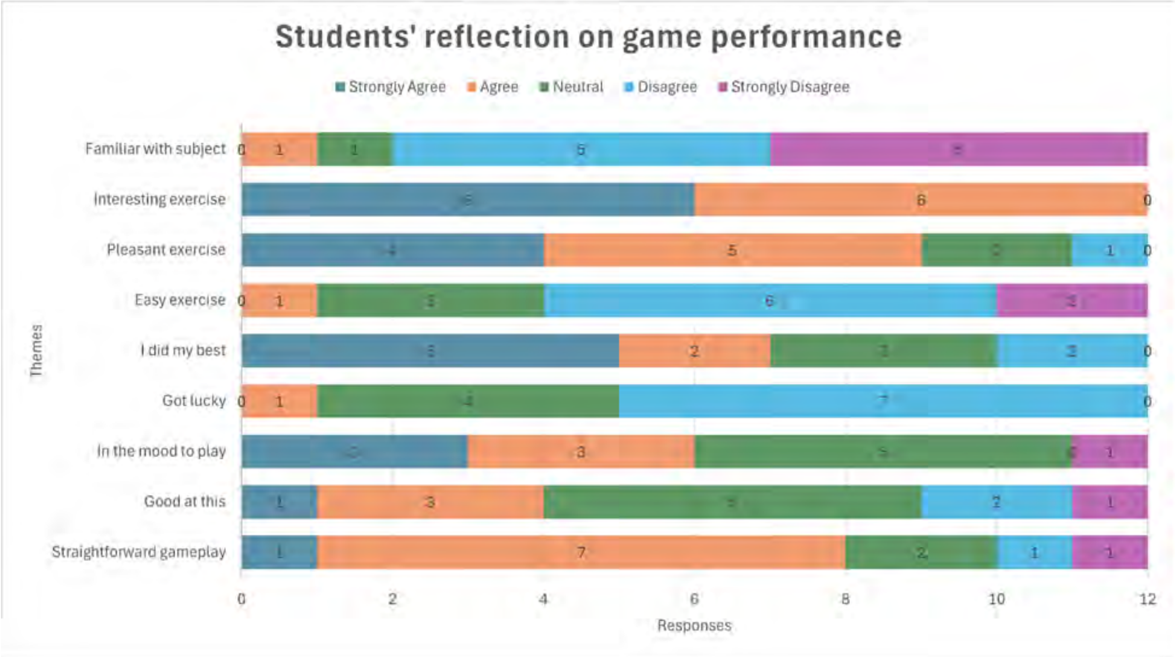

Figure 16: Students' reflection on game performance

Regarding the limited storage space, some students observed patterns that helped them play more efficiently. When asked about their strategy, their accounts were as follows:

> *"making sure I manage my limited resource space and knowing what to keep because I might need it for the future while removing other resources I don't need to make room for the ones I do need" (S8)*

> *"Procure from standard supplier at first. Buy stuff for later stages from the economic supplier. Buy labor last since their contracts expire faster than the equipments'/materials decay" (S12).*

In sum, students' reflections share crucial insights into how players think and consequently how learners approach a new subject. The core gameplay loop was deemed simple yet challenging, striking a balance that is often difficult to achieve. However, there were some aspects of the game that needed more revision, specifically within the usability dimension.

6.6 Evaluating the Usability Dimension

The user interface received mixed comments from the respondents. On the surface level, professors (I6, I7), industry professionals (I8, I9, I11), and some students (S10. S11) commended the *overall look* or called it *impressive* for a first-time developer. On user interface, they rated each UI element for how clear or confusing it was to interact with (see Figure 17). Most UI elements were considered *very clear* or *somewhat clear*. *Error Messages* and the *Manager's Manual* went unnoticed by a handful of players, suggesting that the game may have lacked proper signals to alert the player. Some participants mentioned that the error messages did not remain on the screen long enough to be read fully. In addition, the lack of sound effects could be part of the issue as well.

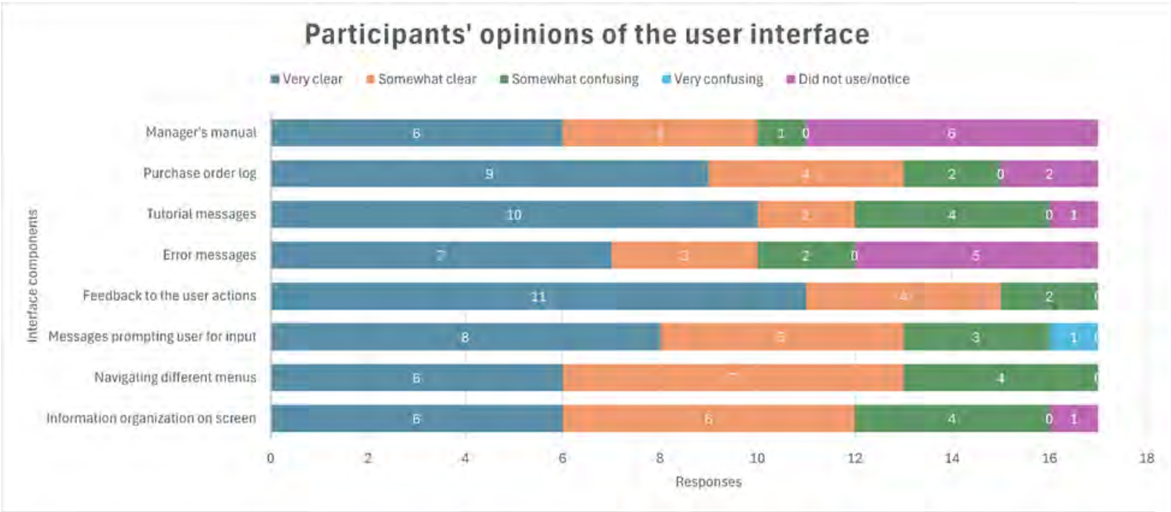

Figure 17: Participants' opinions of user interface

Although the content and gameplay met the learning objectives of the game, several players struggled at the start to get acquainted with the simulation. 5 students suggested having a more interactive tutorial, and this statement was also common among the play-testers from the pilot study. The current tutorial is a text-based set of instructions with screenshots of the user interface. A fellow game developer [S9] commented:

> *"[it is] generally a bad practice to have essay blocks as tutorials, a better approach would be a "guide step-by-step" tutorial where the tutorial teaches the player as he's playing the game."*

6.7 Evaluating the Environment Dimension

The environment dimension is concerned with the technical requirements to run the game as well as the context for playing the game. In this study, all players accessed the game in-browser on their own devices. When asked about classroom implementation, one professor suggested three different scenarios: as a group in-class activity for first-year students, as an individual assignment for second-year students, and as a formal assessment tool for final year students. Many respondents considered the game suitable for the university level. Five respondents mentioned that the game shows promise as a commercial product. One respondent suggested adding complexity tailored to the specific needs of contractors. Likewise, another respondent suggested that companies with graduate programs may be interested in particular.

7. Summary, Conclusion and Future Work

The aim of this study was to discuss the design method and evaluation results of a single-player digital game called *Always Under Stress* developed with the Godot game engine. The goal of the game was to teach resource management in construction projects. The design development steps, game engine, and workflow were discussed in-depth. Moreover, this study showcased how elements of randomness can be used in an educational game to challenge students' strategic planning and adaptability skills.

Participants generally agreed that their learning experience was positive and enjoyable. The elements of randomness in the game proved to be a formidable challenge, particularly reacting to random risk events. The students' self-reflection mirrored their improvement between pre-test and post-test scores. The core gameplay loop was considered engaging and interesting though the tutorial should be revamped to facilitate onboarding new players. Similarly, the user interface can be made more intuitive. Overall, this outcome places the game prototype in a positive position to move forward with further development.

The goal of every GBL study is to get one step closer to implementation. For digital games, some useful applications would be in online or blended learning classrooms, where the students need more interactive activities to engage with the subject material. For future work recommendations, there is a need for more longitudinal studies to assess the impact of game-based learning in the long term.

Conflict of Interest Statement: The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

Ethics and AI Statement: The authors state that no Artificial Intelligence tool was used in any part of this study. Ethical approvals have been obtained with precautions taken to ensure participants' informed consent and confidentiality.

References

Bay, J.W., 2023. *What is visual scripting, and how is it used to make video games?* [online] Game Industry Career Guide. Available at: <https://www.gameindustrycareerguide.com/how-is-visual-scripting-used-in-games/> [Accessed 7 May 2023].

Burgun, K., 2018. *Three types of bad randomness, and one good one*. [online] Available at: <https://keithburgun.net/three-types-of-bad-randomness-and-one-good-one/> [Accessed 8 February 2024].

Castronovo, F., Stepanik, N., Van Meter, P.N. and Messner, J.I., 2022. Problem-solving processes in an educational construction simulation game. *Advanced Engineering Informatics*, [online] 52, p.101574. https://doi.org/10.1016/j.aei.2022.101574.

Dib, H. and Adamo-Villani, N., 2014. Serious Sustainability Challenge Game to Promote Teaching and Learning of Building Sustainability. *Journal of Computing in Civil Engineering*, [online] 28(5). https://doi.org/10.1061/(ASCE)CP.1943-5487.0000357.

Dobroskok, I., Rzhevska, N., Ayyildiz, H., Zaimova, D. and Zheliazkov, G., 2020. Game development software tools in higher educational institutions: experience of Ukraine, Turkey and Bulgaria. *Information Technologies and Learning Tools*, 78(4), pp.90–104. https://doi.org/10.33407/itlt.v78i4.3370.

Elenany, Y. and Ahmed, V., 2023. A Proposed Framework for the Classification of Game-Based Learning in Construction Management. *European Conference on Games Based Learning*, 17(1), pp.799–806. https://doi.org/10.34190/ecgbl.17.1.1712.

Fumarola, M., van Staalduinen, J.-P. and Verbraeck, A., 2012. A Ten-Step Design Method for Simulation Games in Logistics Management. *Journal of Computing and Information Science in Engineering*, 12(1). https://doi.org/10.1115/1.3617440.

Itch.io, 2023. *Most used Engines*. [online] Itch.io. Available at: <https://itch.io/game-development/engines/most-projects> [Accessed 7 May 2023].

Kandi, V.R., Castronovo, F., Brittle, P., Mastrolembo Ventura, S. and Nikolic, D., 2020. Assessing the Impact of a Construction Virtual Reality Game on Design Review Skills of Construction Students. *Journal of Architectural Engineering*, [online] 26(4). https://doi.org/10.1061/(ASCE)AE.1943-5568.0000434.

Kriz, W.C., 2017. Historical Roots and New Fruits of Gaming and Simulation. *Simulation & Gaming*, 48(5), pp.583–587. https://doi.org/10.1177/1046878117732845.

Lee, Y.Y.R., Samad, H. and Miang Goh, Y., 2020. Perceived Importance of Authentic Learning Factors in Designing Construction Safety Simulation Game-Based Assignment: Random Forest Approach. *Journal of Construction Engineering and Management*, [online] 146(3). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001779.

Miettinen, T., Salmi, J., Gupta, K., Koskela, J., Kauttio, J., Karhela, T. and Ruutu, S., 2016. Applying Modelica Tools to System Dynamics Based Learning Games: Project Management Game. *Modelling and Simulation in Engineering*, [online] 2016, pp.1–13. https://doi.org/10.1155/2016/8324914.

Ojiako, U., Ashleigh, M., Chipulu, M. and Maguire, S., 2011. Learning and teaching challenges in project management. *International Journal of Project Management*, 29(3), pp.268–278. https://doi.org/10.1016/j.ijproman.2010.03.008.

Oo, B.L. and Lim, B.T.-H., 2016. Game-based learning in construction management courses: a case of bidding game. *Engineering, Construction and Architectural Management*, [online] 23(1), pp.4–19. https://doi.org/10.1108/ECAM-02-2015-0029.

Pereira, E. and Thom, N., 2022. Teaching Construction Project Planning and Control Using a Management Game Approach. In: *Lecture Notes in Civil Engineering*. [online] Singapore: Springer. pp.59–69. https://doi.org/10.1007/978-981-19-0968-9_5.

Perini, S., Luglietti, R., Margoudi, M., Oliveira, M. and Taisch, M., 2018. Learning and motivational effects of digital game-based learning (DGBL) for manufacturing education –The Life Cycle Assessment (LCA) game. *Computers in Industry*, [online] 102, pp.40–49. https://doi.org/10.1016/j.compind.2018.08.005.

Tahir, R. and Wang, A.I., 2020. Codifying Game-Based Learning: Development and Application of LEAGUE Framework for Learning Games. *Electronic Journal of e-Learning*, [online] 18(1). https://doi.org/10.34190/EJEL.20.18.1.006.

Wall, J. and Ahmed, V., 2008. Use of a simulation game in delivering blended lifelong learning in the construction industry – Opportunities and Challenges. *Computers & Education*, [online] 50(4), pp.1383–1393. https://doi.org/10.1016/j.compedu.2006.12.012.

Wilson, L., 2019. *Godot, Unity, Unreal Engine, CryEngine? Which Game Engine Should I Choose?* [online] medium.com. Available at: <https://medium.com/@thelukaswils/godot-unity-unreal-engine-cryengine-which-game-engine-should-i-choose-553f8ff7999f> [Accessed 7 May 2023].

