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LEARNING SUSTAINABLE CONSTRUCTION PRINCIPLES BY BUILDING A LEARNING-GAME

TEACHING GEN Z CIVIL ENGINEERS CONFERENCE

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Abstract. Growing concern about sustainability has made it essential to incorporate the principles of sustainable construction into engineering curricula, ensuring that future professionals are well-equipped to deal with the multidisciplinary challenges of the 21st century. Moreover, fostering a broader societal understanding of sustainable construction is equally important, as public awareness can drive demand for more environmentally responsible buildings. To address both objectives, an experiential learning strategy was adopted in the Fundamentals of Sustainable Construction course. Over the semester, students developed a board game designed to teach key concepts of sustainable construction to high school students. The game was then tested with a class of 9th-grade students (aged 14–15) to evaluate its effectiveness. This research highlights an active learning approach where university students not only deepen their understanding of sustainability but also build critical skills—such as analytical thinking, communication, teamwork, and creativity—while contributing to public education and awareness of this pressing societal issue.

1 INTRODUCTION

The construction industry is one of the most resource-intensive sectors worldwide, significantly contributing to global energy consumption and greenhouse gas emissions. The importance of sustainable construction is acknowledged by the United Nations (UN) in its 2030 Agenda for Sustainable Development, particularly through the Sustainable Development Goals (SDGs) [1]. Among these, SDG 11: Sustainable Cities and Communities directly targets the transformation of urban spaces into inclusive, safe, resilient, and sustainable environments. Cities are recognized as engines of economic growth, innovation, and social progress; however, they also face major challenges such as environmental degradation, resource depletion, and social inequality. Sustainable construction is central to addressing these challenges. Through strategies such as the use of environmentally friendly materials, reduction in energy consumption, and incorporation of renewable energy sources, the environmental footprint of the built environment can be significantly reduced. These practices not only contribute to the creation of healthier living spaces but also enhance the long-term resilience and quality of life in urban areas.

Sustainable construction is a comprehensive approach to the design, construction, and operation of buildings that emphasizes environmental responsibility, resource efficiency, and economic viability. It involves the use of sustainable materials, energy-efficient technologies, and environmentally friendly practices throughout the building's entire lifecycle—from site selection and design to construction, operation, and eventual deconstruction. This approach can be regarded as a complex engineering challenge, requiring the integration of multiple disciplines such as civil engineering, architecture, environmental science, materials science, and energy engineering. Addressing such complexity in education often demands non-traditional pedagogical methods [2, 3, 4, 5].

One particularly effective approach is active learning, which promotes student engagement, critical thinking, problem-solving skills, and long-term knowledge retention [6]. By encouraging learners to take an active role in their education, this methodology fosters a deeper understanding of content and its real-world applications. When active learning is aligned with the principles of sustainable construction, it creates powerful opportunities to prepare and inspire future professionals in the construction industry [7, 8]. This synergy not only enhances educational outcomes but also promotes a lasting commitment to sustainable practices—potentially driving transformational change within the sector toward a more responsible built environment.

In recent years, the use of games in education has gained popularity as a strategy to engage and motivate learners. Educational games, or learning games, are designed specifically to facilitate knowledge acquisition through interactive and immersive experiences. A promising approach to address this challenge is learning by making a learning game—a specialized form of active learning where students are not only players but also designers and developers of educational games. By engaging in the process of designing games, learners develop a deeper understanding of both the educational content and the mechanics that make the game effective. This approach empowers students to think critically about how to communicate key concepts, while also contributing feedback to improve the game's learning potential.

"Learning by making games" has been successfully applied across a wide range of educational levels—from primary education to higher education—and in diverse subject areas such as science, mathematics, social studies, and language arts [9, 10, 11, 12, 13]. It also facilitates the integration of digital technologies into the learning process, as students often utilize software tools to create their games. The method has demonstrated positive impacts on student engagement, motivation, and learning outcomes, while simultaneously nurturing creativity, teamwork, and problem-solving abilities. Despite its many advantages, implementing this approach also presents challenges, including the need for proper support and guidance, the technical complexity of game development, and the requirement for sufficient time and resources. Nonetheless, when appropriately supported, learning by making games offers a highly engaging and effective educational experience [14, 15].

2 EDUCATIONAL APPROACH AND IMPLEMENTATION STRATEGY

An active learning strategy, known as learning by making games, was implemented in a university-level course on sustainable construction. In this course, students were challenged to design and develop an educational game aimed at teaching high school students about sustainable construction practices. The target audience—high school students aged 14 to 15—

was deliberately chosen, as learners at this age typically possess sufficient cognitive maturity and environmental awareness to engage meaningfully with complex topics. This allowed the university students to develop games that incorporated challenging mechanics and thoughtful question design, enhancing both the educational depth and engagement level of the final product.

By integrating game design with active learning principles, the initiative inspired university students to take ownership of their learning while translating their technical knowledge into an accessible and interactive format for a younger audience. This real-world application of active learning provided students with hands-on experience in both the technical content of sustainable construction and the process of educational game development. At the same time, the activity contributed to the broader objective of raising awareness and fostering understanding of sustainability principles in the built environment among the next generation.

The course "Fundamentals of Sustainable Construction" was part of the Built Heritage Restoration bachelor's degree program at the University of Aveiro. It is an elective course with a weekly schedule of three contact hours, typically attracting a smaller group of students who opt in voluntarily. In the academic year under consideration, the course had a total enrollment of 11 third-year students. At this stage in their studies, students are expected to be familiar with a range of sustainable construction techniques commonly applied. These include the use of renewable materials, strategies for reducing waste, water and energy conservation, passive design methods, and approaches that promote social equity within the building process.

At the beginning of the semester, students were introduced to a unique project-based learning opportunity: to design and develop an educational game on sustainable construction aimed at high school students. The target school was selected based on an existing collaborative relationship. The project served a dual purpose: first, to deepen the university students' understanding of sustainable construction concepts through the process of game development; and second, to raise awareness among high school students about sustainability issues in the built environment. Through this initiative, students were not only able to consolidate their own knowledge but also contribute meaningfully to environmental education for younger audiences.

2.1 Educational approach

The pedagogical approach adopted in the course was designed to promote autonomous and active learning among students. The course started with foundational concepts related to sustainable construction introduced through traditional lectures, providing a baseline of knowledge. From this point, students were encouraged to explore these concepts independently, deepening their understanding while simultaneously engaging in a hands-on game development project. The development of the game followed a collaborative and iterative process, with students working in teams to transform their ideas into a functional and educational board game that integrated key concepts of sustainable construction. Due to the small class size, the students were organized into two groups, each tasked with designing and developing a unique educational game. This arrangement fostered collaborative learning within each group while also creating an environment conducive to deeper exploration of the subject matter. To further motivate student engagement, a friendly competition was introduced between the two groups, with the aim of selecting the best game based on a set of predefined criteria. This competitive dynamic served to heighten interest and participation, enriching the overall learning experience.

Students responded positively to the course structure and exhibited strong enthusiasm throughout the semester. The game development process itself was strategically divided into sequential phases, enabling a clear and organized workflow. These stages offered students a concrete framework and helped maintain focus and direction as they progressed through the project. The step-by-step structure not only facilitated effective project management but also encouraged students to understand the interconnected dimensions of sustainable construction. By navigating through each phase, students gained a more integrated and systems-oriented perspective of the topic.

Table 1. Phases of game development process and associated skills/competences.

Phase	**Skills/Competences**
1. Idea for the game.	Students were encouraged to brainstorm and create innovative game ideas that effectively incorporated sustainable construction concepts. This stage stimulated their creativity and critical thinking skills, enabling them to devise unique and engaging game mechanisms.
2. Questions for the game.	Students had to develop a set of well-researched questions and challenges that focused on sustainable construction principles. This step honed their research skills, content development abilities, and understanding of the core concepts.
3.Building the game.	Students were tasked with constructing the game board that would serve as the visual representation of the game. This phase allowed them to exercise their design and problem-solving skills, as they created an aesthetically pleasing and functional game board, enhancing teamwork and communication skills.
4. Assessing the game at university.	Rigorous assessment of the game was conducted to evaluate its functionality, user experience, and alignment with the learning objectives. Students refined their attention to detail, analytical thinking, and ability to iterate and improve based on feedback.
5. Adjusting the game.	Fine-tune and adjust the game mechanics based on the feedback received during assessment phase. Based on the insights gained from the assessment, students iterated on the game mechanics to enhance gameplay and ensure alignment with sustainable construction concepts. This stage cultivated their adaptability, flexibility, and ability to make informed decisions for game improvement.
6. Assessing the game at high school.	Organize a trial run of the game at a high school, allowing the target audience to experience and provide feedback on the game. This step provided students with an opportunity to observe the game's impact on the players, while also developing their communication and observation skills.
7. Make a background document.	Students created a comprehensive background document that elucidated the purpose, objectives, rules, and educational value of the game. This stage fostered their technical writing skills, organization, and ability to effectively communicate the game's educational aspects.

The sequential phases of the game development process are presented in Table 1. These stages were designed to support the systematic creation of the games, while also aiming to develop a broad range of competencies—including critical thinking, project planning, teamwork, communication, and creative problem-solving.

2.3 Implementation strategy for the game development

During the initial conceptualization phase, students engaged in brainstorming sessions to explore various gameplay mechanisms and approaches for engaging high school students. Their goal was to design a game that was both enjoyable and effective in communicating the principles of sustainable construction.

Once the game concept was defined, students progressed to the question development stage. This involved researching sustainable construction practices, selecting relevant topics, and crafting questions that were both informative and intellectually stimulating. Each question was designed to assess players' knowledge while also promoting reflection and critical thinking about sustainability in construction.

Following this, attention turned to the physical design and construction of the game board. Students aimed to create an engaging and visually appealing layout that would enhance the player experience. Care was taken to ensure that the design elements of the game board clearly represented concepts of sustainable construction and supported players' understanding of the subject matter

Figure 2: Board design of the games *SustHouse* and *EcoBlock*

The games developed were titled "A Casa Sustentável" ("The Sustainable House", referred to as *SustHouse* in this article) and "*EcoBlock*" (see Figure 2). Following their development, the project moved into the game assessment phase, during which students evaluated the functionality, usability, and educational effectiveness of their creations. They conducted internal playtests, critically analyzing the gameplay experience and collecting feedback from peers and instructors to identify areas for improvement. This iterative process enabled them to refine game mechanics, resolve design issues, and improve the clarity and engagement of the content. In addition to self-assessment, each group was also tasked with evaluating the game developed by the other team, fostering a constructive exchange of ideas and promoting critical reflection on different approaches to conveying sustainable construction principles.

After incorporating the necessary refinements identified during the assessment phase, the students had the opportunity to test their games in a real high school classroom setting. Implementing educational games in such environments requires consideration of several critical factors. First, the usability and functionality of the game must be evaluated, including the clarity of instructions, ease of use, and the overall responsiveness of the game materials. These aspects

were assessed through direct observation and user feedback, providing valuable insights into the design and user experience. Another essential consideration was the level of engagement and motivation the game could foster. Educational games must strike a balance—being sufficiently challenging to sustain interest while remaining accessible to prevent frustration. To evaluate the game's effectiveness in promoting learning and engagement, a short quiz was administered at the end of the session.

This hands-on experience with the target audience proved invaluable. It enabled the university students to gather immediate and authentic feedback, observe how well the sustainable construction concepts were conveyed, and assess the overall educational impact of their games. Through direct interaction with the high school students, they could refine their understanding of user-centered design and evaluate the educational relevance of their work in a practical context.

3 RESULTS AND DISCUSSION

3.1 University student's perspectives

At the end of the course, university students were invited to reflect on their learning experience. Given the relatively small group size, a statistical analysis was not conducted; instead, the main qualitative insights are presented here. A key highlight for the students was the opportunity to present their games to high school students, which provided valuable feedback from a younger and distinct audience. They appreciated engaging with participants who offered fresh perspectives and honest reactions to the games. Visiting the high schools was also a rewarding experience: it allowed university students to inspire and connect with younger learners who shared an interest in sustainability and construction. This interaction not only promoted awareness of sustainable construction practices but also promoted a sense of responsibility and mentorship among the university students. Many described the experience as both enjoyable and meaningful, especially noting the seriousness and thoughtful feedback provided by the high school students. While not directly related to the course objectives, these experiences contributed to the development of key soft skills such as communication, empathy, adaptability, teamwork, and active listening.

Additionally, students expressed strong appreciation for the course's active and creative learning approach. A particularly valued aspect was the freedom to explore and express their creativity throughout the game development process. This creative autonomy encouraged ownership, engagement, and pride in their work. The opportunity to translate ideas into tangible results made the learning experience more personal and memorable. Creativity, though often underemphasized in engineering education, is essential in fostering innovation and problem-solving [16, 17]. The students' feedback confirmed that the emphasis on imagination helped them build confidence and resilience while enhancing their analytical and critical thinking skills—key outcomes of problem-based learning methodologies [18, 19]. However, one of the most common concerns raised by students was the potential loss of depth in theoretical knowledge. Some felt that, while the hands-on, project-based format was enriching, it may have come at the expense of a deeper understanding of core sustainable construction concepts. This observation highlights the importance of balancing practical activities with solid theoretical grounding. While experiential learning develops applied skills, theoretical instruction remains essential for building comprehensive knowledge [20]. This suggests that future editions of the

course could benefit from more structured theoretical components or supplemental resources to reinforce key concepts.

Finally, students noted the value of the background document they created alongside their board games. This resource, which summarized and organized the theoretical principles of sustainable construction, proved to be instrumental in consolidating their learning. It not only reinforced their understanding during the course but also served as a tangible, reusable reference, supporting both basic comprehension and more advanced exploration of the subject.

3.2 Feedback from target learners

To gain insight into high school students' opinions about the games, the teacher distributed an anonymous quiz at the end of the session to those willing to participate. A total of 28 responses were collected – 14 for each version of the game. Students were informed that the purpose of the quiz was solely to gather feedback on their experience playing the game. The survey addressed various aspects, including game mechanics and the educational objective of learning about sustainable construction. Responses were recorded using a Likert-type scale ranging 1 to 10. A translated version of the quiz is presented in Figure 3.

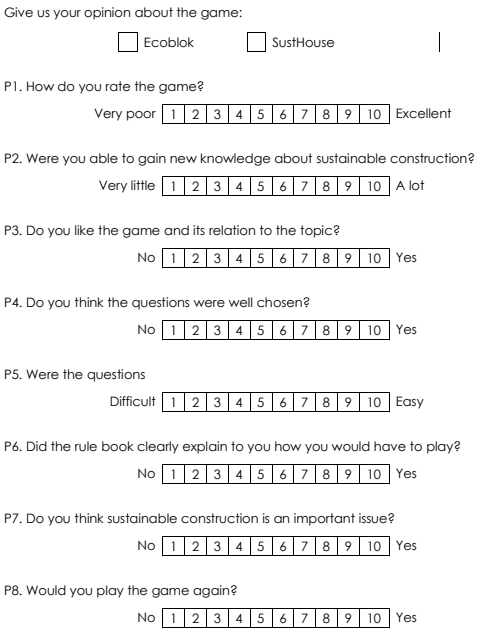


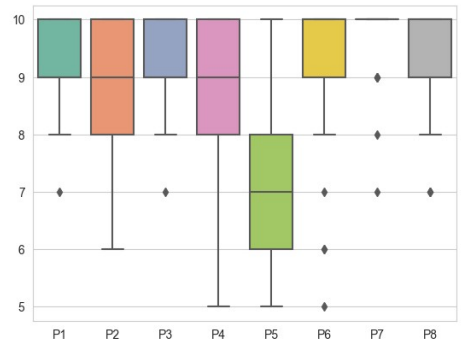
Figure 3: High school students feedback quiz

The summary of responses—including means, standard deviations, quartiles, and minimum and maximum values—is presented in Table 2. It is notable that the 75th percentile is 10 for all questions except for question P5, indicating that students generally enjoyed playing the game and found it useful. Particularly significant is question P8, which asked about the likelihood of playing the game again; this item recorded the highest mean score and a median of 10.

Regarding question P5, which inquired about the difficulty of the questions, it can be observed in Figure 4 that it has a clearly different distribution. This question exhibited the

widest range of answers, with most responses clustered around the middle of the scale (between 4 and 6). The mean score of 6.8 and median of 6 suggest that the question difficulty was appropriate for the students.

The suggestions provided by high school students primarily focused on two key areas. First, they indicated that the game's rules could be improved to enhance the overall gaming experience. This feedback reflects students' specific ideas for modifying or refining the rules to make the game more engaging, challenging, and enjoyable. Second, students expressed interest in seeing the game commercialized, implying that they found it compelling and entertaining enough to appeal to a wider audience beyond their own high school. This suggestion highlights their perception of the game's potential value and its prospects for success in a broader market.



	P1	P2	P3	P4	P5	P6	P7	P8
mean	9.21	9.03	9.29	8.79	6.82	9.25	9.68	9.32
stddev	0.83	1.11	0.81	1.29	1.492	1.46	0.72	1.06
min	7.0	6.0	7.0	5.0	5.0	5.0	7.0	7.0
25%	9.0	8.0	9.0	8.0	6.0	9.0	10.0	9.0
50%	9.0	9.0	9.0	9.0	7.0	10.0	10.0	10.0
75%	10.0	10.0	10.0	10.0	8.0	10.0	10.0	10.0
max	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

Figure 4: Summary statistics of quiz answers

The correlation matrix shown in Figure 5 illustrates the relationships between the quiz responses. It is evident that questions P1 to P4 and P6, which pertain to the game mechanics, exhibit the highest correlations. In contrast, questions P5, P7, and P8 show the lowest correlations, with P5 being the least correlated. These results suggest that the games were well-designed and provided an enjoyable playing experience.

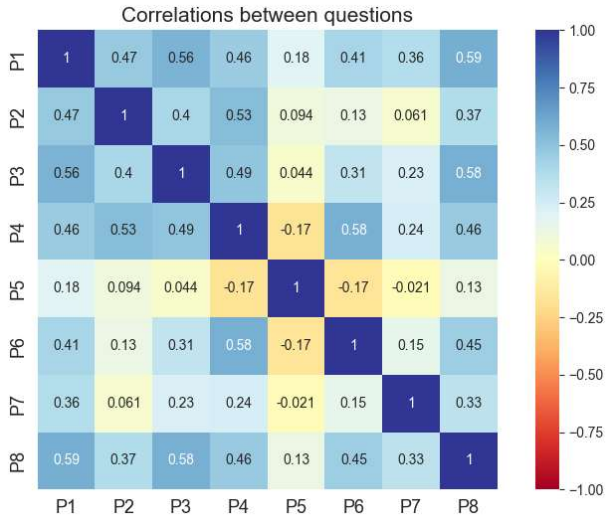


Figure 5: Statistical correlations of answers

Based on the quiz outcomes and analysis, it can be concluded that the games implemented for high school students were well received and appreciated by the participants. The strong correlations and consistent responses related to game mechanics indicate that the design effectively engaged the students' interest and participation. These insights may prove valuable for educators and developers aiming to create compelling and educational experiences for high school learners.

4 CONCLUSIONS

- The active learning strategy of learning by making a learning game—applied here in the context of Sustainable Construction—demonstrated its effectiveness and potential for broader implementation. This approach can be extended to other subjects within Civil Engineering curricula, as well as to other engineering disciplines, offering a flexible and impactful method for active learning.
- The creation of educational board games emerges as a valuable pedagogical tool. The process promotes teamwork and collaboration, boosts student motivation and engagement, and allows for a personalized, hands-on learning experience.
- Student feedback highlighted the importance of striking a balance between structure and creativity, the value of thorough preparation, the use of tangible learning resources, and the benefits of engaging with diverse audiences. These insights suggest that, by integrating these elements, educators can significantly enhance the learning experience—supporting students in developing a well-rounded understanding of key concepts, encouragement creativity, and preparing them for practical, real-world challenges.
- The development of educational board games represents a cost-effective and gratifying method to teach a wide array of subjects and skills, making it a versatile addition to any educator's toolkit.

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