Serious game on bio-based construction materials: design, development and testing

Roberta Salierno*, Margherita E. P. Pero*, Monica Rossi*, Ingrid M. Paoletti**

** Department of Management Engineering, Politecnico di Milano, via Raffaele Lambruschini, 4/B, 20156 Milano MI, Italy*

roberta.salierno@polimi.it,

margherita.pero@polimi.it,

monica.rossi@polimi.it,

*** Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, via Giuseppe Ponzio, 31, 20133 Milano MI, Italy*

ingrid.paoletti@polimi.it

Abstract: Pollution in the construction sector is a significant issue with implications for various environmental aspects and human health. Construction activities generate a wide range of pollutants throughout the life-cycle with different effects in different phases, including atmospheric emissions, waste production, natural resource consumption, and environmental disturbances. As consciousness of construction-related impact grows, the adoption of bio-based materials emerges as a viable solution. To enhance their diffusion, it is necessary to address awareness surrounding both the impacts of the construction sector and the materials themselves. Consequently, this study presents an innovative approach to enhancing awareness on the potential of bio-based materials in construction through a serious game. The board game is developed to compare clay and hempcrete construction blocks, in two different steps. In the first part, participants are asked to evaluate the life cycle of the products identifying their main phases and relative steps, while the second part focuses on the evaluation of their impacts in terms of different environmental aspects. The game's structure was developed to engage participants and foster knowledge regarding the utilization and benefits of bio-based materials in construction practices. To validate its structure organization and gather feedback, a preliminary test was conducted, involving participants from diverse backgrounds. Throughout the preliminary test, participants interacted with the game, experiencing its various components and challenges. Feedback were collected through structured discussions and notes, allowing for a comprehensive assessment of the game's impact. Analysis of the data revealed promising results, indicating a positive reception of the game among participants. Moreover, constructive feedback provided valuable insights for refining and improving the game's design and contents. This study aims to contribute to the field of educational gaming, demonstrating the potential of gamification as a tool for promoting awareness and education on sustainable construction practices and bio-based materials.

Keywords: Serious Games, Life-cycle assessment, bio-based materials, construction

1.Introduction

Climate change and the high emissions associated with the construction sector pose significant challenges to global sustainability efforts. The construction industry contributes significantly to greenhouse gas (GHG) atmospheric emissions (World Green Building Council, 2019). For instance, the residential sector accounts for 27% of global energy consumption (Nejat et al., 2015). Construction products generate 23% of human-related GHG emissions (Abergel et al., 2017), with more than half of those coming from cement and steel manufacturing, substantially contributing to climate change.

In response, bio-based materials have emerged as a potential solution, offering environmentally friendly alternatives derived from renewable resources (Pittau et al., 2018; Carcassi et al., 2022). Despite their promise, integrating bio-based materials into construction practices is challenging. One aspect to consider is the technical challenges associated with their organic nature, such as durability and production (Sandak et al., 2019). Furthermore, barriers to a broader diffusion are associated with a disconnected supply chain (Gosselin et al., 2017) and a widespread lack of awareness on the potential of these materials and their applications in construction (Göswein et al., 2022; Markström et al., 2016). Therefore, as the lack of awareness among several construction actors represents one of the significant barriers towards a more widespread diffusion of bio-based materials in construction, further investigation is needed to address this gap. To tackle the different stakeholders involved in the ecosystem and provide an easy way of learning, this article presents a serious game called "Bio-based materials awareness game". This game is based on life-cycle assessment (LCA) as it represents a widely recognized methodology to evaluate the environmental impacts of products or services throughout their life cycle. Several studies have applied LCA methodologies to assess the environmental impacts of construction projects, building materials, and infrastructure (Quintana-Gallardo et al., 2020; Heidari et al., 2019; Barrio et al., 2021). Some materials reduce the overall building impact throughout their life cycle (Vilches et al., 2017), while also considering other aspects, such as local availability and occupants' wellbeing (Liu et al., 2017). For these reasons, research interest towards bio-based materials and their potential in construction is increasing as they could represent a significant opportunity for reducing environmental impacts and promoting sustainable construction practices and positive social impacts.

The remaining portion of the article is structured as follows: in the following section, a literature background is given on the topics of serious games and bio-based materials in construction. Subsequently, the methodology of producing the game and gaining feedback through a preliminary test is explained. The results and discussion section provides the main insights from the preliminary test while following future research is outlined.

2. Literature background

2.1 Serious games

When it comes to enhancing knowledge by leveraging new ways of learning, serious games may represent an important and innovative tool. While literature refers to these tools in several other ways, e.g., "educational games", "simulation games", and "edutainment" (Kerga et al., 2014), gradually, research has increasingly focused on the exploration of the integration between entertainment and education (Jiang and Shangguan, 2022). Particularly, Connolly et al. (2012) have underscored the influence of serious games on learners, including perceptual, behavioural, emotional, and motivational dimensions. Their work notably accentuates the pivotal role of educational games in fostering knowledge acquisition and enhancing content comprehension. Similarly, while comparing serious and casual games, Boyle et al. (2016) reveal a substantive difference in their impact on knowledge acquisition, pointing out that the former contributes to knowledge learning.

Serious games are designed with the primary purpose of educating or training users on specific concepts or knowledge areas while engaging them in gameplay (Charsky et al., 2010). These games combine entertainment elements with educational content to create engaging learning experiences, aiming to teach specific skills or knowledge areas relevant to academic subjects or professional development (Jiang and Shangguan, 2022). Serious educational games leverage interactive gameplay mechanics to engage players actively in the learning process. They often involve problem-solving, critical thinking, and decision-making activities. Effective serious games provide feedback to players on their performance, helping them understand their strengths and areas for improvement. This feedback can be immediate or provided at various points throughout the game. Many serious games incorporate real-world scenarios or simulations to contextualize learning content and help learners understand its practical applications.

When it comes to climate change and environmental awareness, Kwok (2019) highlights that the effects of games based on the life cycle of services or products may shift attitudes regarding global warming and may correlate with alterations in students' daily behaviours. In fact, while it is customers are used to evaluating the impact of a product during the operational phase (Kurisu et al., 2021), research widely highlights the importance of focusing intensively on other stages, such as the production processes, as underscored by (Hondo et al., 2008).

Bascoul et al. (2013) proposes a serious game evaluating the environmental impact of products encompassing all their life cycle. Adding to this, we designed a game that evaluates the environmental impact of construction products, aiming to promote awareness of more sustainable solutions with regard to construction practices.

2.2 Bio-based materials in construction

Bio-based materials are a promising alternative to traditional construction materials as they are made from renewable biological resources such as crops, wood, and

microorganisms. This makes them a more sustainable alternative because of their lower carbon footprint and their overall reduced impact on the environment, for example, in terms of waste that goes into landfills (Carcassi et al., 2022).

Bio-based materials can be utilized in various applications, including insulation, flooring, and building components. In addition to their reduced environmental impact, they also have improved performance characteristics such as insulation and fire resistance. For instance, a bio-based material is cross-laminated timber (CLT), which is made from solid wood panels glued together in alternating directions to form a strong and stable building material. CLT is lighter than concrete and steel and has a lower carbon footprint, making it an attractive alternative for use in construction. Another example is hemp-based insulation, which is made from the inner fibres of the hemp plant (Heidari et al., 2019). It has excellent insulation properties and is also an excellent air purifier, making it an environmentally friendly choice for building insulation. Moreover, several studies have been conducted on the effectiveness of mycelium, the root part of fungi, as a material used for insulation as well as for internal partitions (Cerimi et al., 2019).

The utilization of bio-based materials in the construction industry is becoming increasingly important as the demand for sustainable building solutions grows. However, several barriers inhibit their use in construction. For instance, there is a widespread lack of awareness towards these solutions among construction professionals, making it difficult to promote their wider use. This can be addressed through education and outreach efforts (Göswein et al., 2022; Markström et al., 2016).

Technical challenges are also to be considered, as bio-based materials can be more difficult to process and handle than traditional materials, leading to technical difficulties in production and implementation (Sandak et al., 2019). Moreover, since they often depend on the prices of the raw materials used to produce them, the cost and price of bio-based materials can be volatile. Furthermore, these products are not widely available, and the supply chain for these materials is still in its early stages of development. In this context, focusing on enhancing awareness may play an essential role in fostering their widespread adoption.

3. Methodology

3.1 Development of the board game

While giving insights into the implications of the construction sector's environmental impact, the game's main objective is to raise awareness of the potential for new, more sustainable materials and solutions among the sector's stakeholders. To achieve this goal, while playing the game, the players will learn how to read and use EPDs (Environmental Product Declarations), which represent a valuable tool to address the impact of products and have become fundamental for construction products.

The game targets the life-cycle assessment of products, specifically to compare traditional clay and hempcrete bricks, addressing their life-cycle stages and different environmental indicators to compare their impact. In this phase, players are supposed to play with a maximum range of participants from fifteen to sixteen people. The choice has been made to enhance discussion among players and facilitate interaction throughout the game.

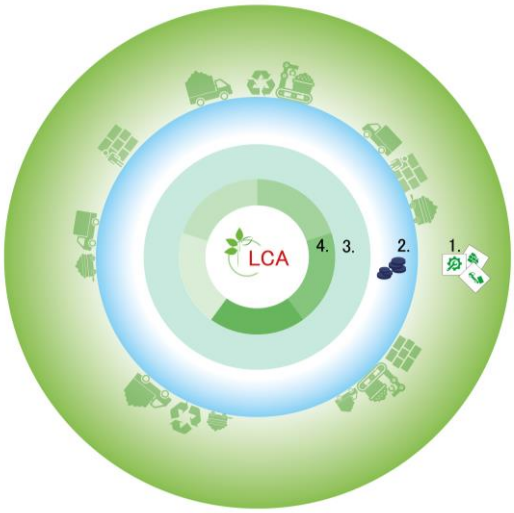

Figure 1: board game

Figure 1 shows the board game design, which consists of two phases which address the chosen products' life-cycle stages and environmental impacts. The numbers on the board refer to:

1. Activities: hypothesis;

2. Impacts: hypothesis;

3. Activities: solution;

4. Impacts and stages: solution.

Before addressing the two construction products above, participants will play with the game facilitator for a trial run, considering a daily product, a cup of coffee (Bascoul et al., 2013). This choice aims to facilitate understanding of the game's rules and address any possible players' doubts. Subsequently, clay and hempcrete bricks are addressed in this sequence. At the end of every stage, a breakdown of the results is provided to reflect on the responses and differences and similarities between the two construction products.

The following subsections will explain in depth the phases of the game with regard to the two construction products.

Phase I

The first phase focuses on the life steps of each product. Specifically, the question that the participants need to answer is: "Which are the product life-cycle steps and sub-steps?" Participants will need to identify the main stages associated with each product, positioning the names of the stages on a sticky note along the board. After some

minutes, the first part of the results is shown, and the stages are associated with the once implemented in the product's EPDs. Table 1 below reports the answers.

Table 1: Main steps, solution (clay and hempcrete bricks)

Step1	Production
Step2	Construction
Step3	Use
Step4	End of life
Step5	Reuse/recycling

A short discussion follows to address mistakes and possible questions. Furthermore, the participants are asked to identify all the activities involved in each stage of the product life cycle. The game facilitator will distribute a deck of cards with illustrated activities, where some are not associated with the targeted product, and participants will be asked to place the cards close to the relative life-cycle stage. The results are checked and discussed together in a short breakdown moment before addressing the second phase. Table 2 shows the complete results for the two different materials, while Figure 2 displays the full set of cards.

Table 2: Activities within each step, solution (clay and hempcrete bricks)

Production	A1- Raw material supply; A2- Transport; A3- Manufacturing
Construction	A4- Transport; A5- Construction
Use	B1- use, B2- Maintenance; B3- Repair; B4- Replacement; B5- Refurbishment; B6- Operational energy use; B7- Operational water use
End of life	C1- deconstruction, demolition; C2- Transport; C3- Waste processing; C4- Disposal
Reuse/recycling	D- Reuse, recovery, recycling potential

Figure 2: set of cards (clay and hemp bricks)

Phase II

Phase II concerns the environmental impact of the products and targets three specific environmental indicators: (i) Global Warming Potential (GWP), (ii) net use of Fresh Water (FW) and (iii) Total use of non-renewable primary energy resources (PENRT). These acronyms are coherent with the associated products EPDs to enhance clarification. Furthermore, the indicators were chosen because they represent the indicators most commonly considered to have a simplified yet thorough understanding of a product's impact.

In this phase, participants are asked to estimate the percentage of the impacts in each life-cycle stage of each product. This guessing process is designed to provide a clear and focused understanding of the environmental impact. To facilitate this, players can define a "high, medium, low" percentage, associating different tokens for each step. Figure 3 displays the results for the two products. Once again, a breakdown moment addresses any mistakes and encourages discussion on the given results.

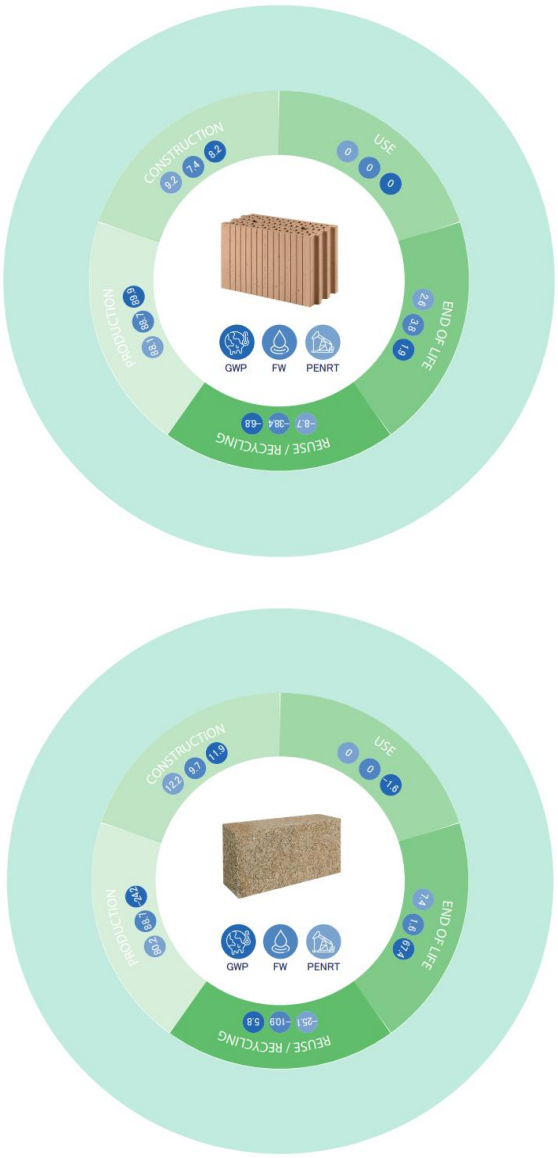

Figure 3: results of phase II (clay and hemp bricks)

3.2 Preliminary test

A preliminary test was implemented to test the feasibility of the game. Seven participants were gathered among PhD students from the Department of Management Engineering of Politecnico di Milano. Having different backgrounds, the sample group was chosen to foster discussion and help the refining process. Furthermore, all the profiles involved are familiar with the "life-cycle assessment" concept. Two players joined the group online, while the others gathered in presence.

Although it might only consider a sample that is only partly representative, this approach results to be practical and straightforward to put into action and to gather initial feedback. The methodology, which will be further implemented by defining a test group and control group and by considering more in detail the level of motivation of participants before and after the test, is thorough and reliable.

The session lasted two and a half hours, and the feedback was collected through notes, implementing both a collective and an individual discussion.

4. Results and discussion

The feedback gathered during the preliminary test highlights several critical points. The information has been organized in clusters.

All participants highlighted that the game enhanced their knowledge and the possibilities of bio-based materials in construction. Additionally, they shared positive feedback, specifying that such an interactive way of learning can bring positive outcomes, although the game might take up to two and a half hours or three hours to complete. Three participants noted that a smaller group size of 3-4 participants may be optimal to reduce the required timing and allow for deeper reflection on the subject matter depending on individual circumstances. Furthermore, playing in groups might reduce the time needed, as different groups focus on a single product and then share the results in the subsequent discussion. Another note implemented by all the participants regards visual representations, which are deemed effective in conveying information, suggesting a need for engaging graphics to enhance comprehension and retention.

Additionally, two participants highlighted the need for more straightforward explanations, particularly regarding terms like EPD, indicating a desire for a learning component within the game. In particular, this suggestion represents a point that requires further investigation, as the group involved in the trial might not be familiar with the construction sector or other topics such as life-cycle assessment (LCAs). Furthermore, another participant underlined the need for thorough explanations of acronyms and their meanings to facilitate understanding. It is reasonable to consider that future players, who will represent the sector's stakeholders, might be already familiar with topics related to product requirements and sustainability practices. It is also to be noted that this game can be played by a group of customers; therefore, in this case, such explanations might be beneficial for the overall goal of the game. In this case, acquiring knowledge on topics such as EPDs or LCAs can represent another objective to aim for.

The group's feedback, particularly regarding the use of cards in Part II, is invaluable. The suggestion to have separate decks of cards for each material to avoid confusion, with a few challenging ones thrown in to stimulate critical thinking, is a testament to the group's integral role in the game's development.

Furthermore, an important point to address is that the feasibility of an online format for the game is questioned, suggesting a potential need for reassessment. The participants who joined online shared their difficulties, particularly with Part II, keeping up with the discussions and choosing the set of cards. This observation led to the choice to eliminate the hybrid version (in presence and online), while the opportunity of carrying out the game

entirely online is still under consideration, given the possibility to share the board and the set of cards digitally.

Lastly, the discussion led to the idea of concluding the session with a breakdown of the additional benefits of hemp products compared to traditional options, in this case, clay ones. Moreover, it would be beneficial to stimulate the sharing of opinions regarding the exploration of potential applications in various sectors like residential buildings, healthcare, and public sectors.

This test allowed the authors to gather preliminary information that is fundamental to starting the future analysis and tests in a complete and prepared way. The next step will be implementing a complete study with a test group and a control group to measure the game's learning impact effectively. Furthermore, a questionnaire to measure the level of motivation and pre-and post-tests will be distributed to assess participants' knowledge.

4. Conclusions and future research

The study presents a novel approach to addressing the lack of awareness surrounding bio-based materials in the construction sector by developing and testing a serious game.

The implementation of a serious game has been proven beneficial when addressing specific problems (Jiang and Shangguan, 2022), given the properties of this educational tool (Kerga et al., 2014). In this case, the board game takes inspiration from the Life-Cycle Perception game (Bascoul et al., 2013). Particularly, the game has been designed to compare clay and hempcrete construction blocks, with the aim to engage participants in evaluating the life cycle and environmental impacts of these materials, highlighting the essential features and properties of bio-based materials for construction applications. Feedback from a preliminary test indicates a positive reception of the game, with suggestions for improvement, including more precise explanations, enhanced visual representations, and consideration of online feasibility. Altogether, the findings suggest that educational gaming holds promise as a tool for promoting awareness and understanding of sustainable construction practices and bio-based materials among diverse stakeholders.

Nevertheless, future research should be implemented to build upon the findings of this study. Firstly, further refinement of the game design based on feedback from stakeholders, including construction professionals, educators, and policymakers, can enhance its effectiveness and usability. Additionally, exploring the potential of online formats for the game while addressing challenges identified during testing can broaden its accessibility and reach. Moreover, investigating the long-term impacts of the game on participants' knowledge retention and attitudes towards bio-based materials can provide valuable insights into its efficacy as an educational tool. Furthermore, extending the game's scope to include other bio-based materials might foster a more profound understanding and engagement with sustainable construction solutions. Broader research in this area can contribute to advancing sustainability efforts in construction and promoting the adoption of bio-based materials on a wider scale.

References

Abergel, T., Dean, B., Dulac, J., 2017. Towards a zero-emission, efficient, and resilient buildings and construction sector: Global Status Report 2017. *UN Environment and International Energy Agency,* Paris, France.

Bascoul, G., Schmitt, J., Rasolofoarison, D., Chamberlain, L., Lee, N., 2013. Using an experimental business game to stimulate sustainable thinking in marketing education. *Journal of Marketing Education*, 35(2) 168–180.

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., Pereira, J., 2016. An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers and Education* 94, 178–192.

Carcassi, O., Habert, G., Malighetti, L.E., Pittau F., 2022. Material Diets for Climate-Neutral Construction. *Environmental Science and Technology*.

Charsky D (2010) From edutainment to serious game: a change in the use of game characteristics. *Games and Culture* 5: 177–198.

Cerimi, K., Akkaya K. C., Polh, C., Schmidt, B., Neubauer, P., 2019. Fungi as source for new bio-based materials: a patent review. *Fungal Biology and Biotechnology*, Springer Nature, 6,17.

Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., and Boyle, J.M., 2012. A systematic literature review of empirical evidence on computer games and serious games. *Computers and Education,* 59, 661–686.

Gosselin, A., Blanchet, P., Lehoux, N., & Cimon, Y. (2017). Main motivations and barriers for using wood in multi-story and non-residential construction projects. *BioResources*, 12(1), 546-570.

Göswein, V., Arehart, J., Phan-huy, C., Pomponi, F., Habert, G., 2022. Barriers and opportunities of fast-growing biobased material use in buildings. *Buildings and cities*, ETH Zurich Collection.

Heidari, M. D., Lawrence, M., Blanchet, P., Amor, B., 2019. Regionalized Life Cycle Assessment of Bio-Based Materials in Construction; the Case of Hemp Shiv Treated with Sol-Gel Coatings. *MDPI, Materials*, 12, 2987.

Hondo, H., Hirayama, Y., Nakajima, K., Yamada, S., Fukuhara, I., 2008. Use of life cycle thinking in environmental education: visualization and recovery of the missing link towards sustainable consumption. *Journal of Life Cycle Assessment.* Jpn. 4 (3), 279–291.

Liu, L., Li, H., Lazzaretto, A., Manente, G., Tong, C., Liu, Q., Li, N., (2017). The development history and prospects of biomass-based insulation materials for

buildings. *Renewable and Sustainable Energy Reviews*, 69, 912– 932.

Jiang, F., Shangguan, D., 2022. Researching and designing educational games on the basis of "self-regulated learning theory". *Frontiers in Psychology*, 13, 996403.

Kerga, E., Rossi, M., Terzi, S., Taisch, M., Bessega, W., Rosso, A., 2014. Teaching set-based concurrent engineering to practitioners through gaming. *International Journal of Product Development*, 19, 5/6.

Kurisu, K., Okabe, H., Nakatani, J., Moriguchi, Y., 2021. Development of board game to encourage life cycle thinking, and trial with university students in Japan. *Cleaner and Responsible Consumption*, 3, 100033.

Kwok, R., 2019. Science and culture: can climate change games boost public understanding? *Proc. Natl. Acad. Sci. Unit. States Am.* 116 (16), 7.

Markström, E., Bystedt, A., Fredriksson, M., Sandberg, D., 2016. Drivers and barriers for an increased use of bio-based building materials in Sweden. Proceedings of the 12th meeting of the Northern European Network for Wood Science and Engineering (WSE). *Wood science and engineering*, 15-21.

Nejat, P., Jomehzadeh, F., Taheri, M.M., Gohari, M., 2015. A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries) *Renewable and Sustainable Energy Reviews*.

Pittau, F., Krause, F., Lumia, G., Habert, G., 2018. Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls. *Building and Environment*, 129, 117-129.

Quintana-Gallardo, A., Alba, J., Del Rey, R., Crespo Amoros, J.E., Guillen-Guillamon, I., 2020. Life-Cycle Assessment and Acoustic Simulation of Drywall Building Partitions with Bio-Based Materials. *MDPI, Polymers*, 12, 1965.

Sandak, A., Sandak, J., Brzezicki, M., Kutnar, A., 2019. Bio-based Building Skin. Environmental Footprints and Eco-design of Products and Processes, *Springer Nature*, Singapore.

Vilches, A., Garcia-Martinez, A., Sanchez-Montã, B., 2017. Life cycle assessment (LCA) of building refurbishment: A literature review. *Energy & Buildings*, 135, 286–301.

World Green Building Council, 2019. New Report: The Building and Construction Sector Can Reach Net Zero Carbon Emissions by 2050. *World Green Building Council*, London.