Leveraging AI to instruct architecture students on circular design techniques and life cycle assessment

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Abstract

The aim of this study is to examine the use of AI as a tool for educating architecture students in circular design principles and life cycle assessment (LCA). A theoretical research approach is proposed to identify current challenges and solutions, and to provide insightful predictions and explanations from various perspectives. The paper emphasises the importance of sustainability in architecture education and assesses the difficulties of teaching circular design and LCA, and how AI can simplify the process. The role of AI in promoting cradle-to-cradle thinking in the design stage is demonstrated through the use of a standard LCA framework to make the assessment process more accessible to students. Key factors such as the building's climatic zone, location, type, service life, energy consumption and CO_2 emissions are considered part of the system boundary. The study concludes with limitations, recommendations, and guidelines for architecture students.

Keywords: Artificial intelligence (AI); circular design techniques; life cycle assessment (LCA); sustainability education; cradle-to-cradle thinking; environmental impact factors.

1. Introduction

In recent years, the architecture profession has been facing the challenge of creating buildings that are not only aesthetically pleasing but also environmentally responsible. Circular design techniques and life cycle assessment (LCA) are two key approaches that aim to promote sustainable design practices, by reducing waste and maximising resource efficiency throughout the lifecycle of a building (Eberhardt, Birkved, & Birgisdottir, 2022; Trusty & Horst, 2002). However, despite their importance, these concepts are often not taught in depth in traditional architecture education, leaving students with limited exposure to their practical applications (Gomes, da Silva, & Kowaltowski, 2022).

Artificial intelligence (AI) has the potential to bridge this gap, by providing students with interactive, data-driven tools that help them to understand the principles and benefits of circular design and life cycle thinking. AI-based educational tools can simulate the impacts of different design choices on the environment and help students to evaluate their designs from a life cycle perspective, in real-time. This type of feedback can be instrumental in promoting the adoption of circular design techniques and life cycle thinking in architecture education, by providing students with a deeper understanding of the trade-offs and opportunities associated with different design choices (Ewa; Gilner, Adam; Galuszka, & Tomasz Grychowski, 2019).

The aim of this study is to address the following questions:

- Why is the inclusion of LCA and circular design strategies in architecture education important and what makes it challenging?
- How can AI be utilized to streamline the implementation of LCA and circular design techniques in architecture education?

Then, the possibility of the development of a method that allows architecture students to easily apply the logic of LCA and circular design strategies at the early design stage is discussed.

2. Why is the inclusion of Life Cycle Assessment and Circular design strategies in architecture education important and what makes it challenging?

The inclusion of LCA in architecture education is important because it equips future architects with the tools and knowledge necessary to create sustainable and environmentally conscious buildings. LCA is a method for evaluating the environmental impact of a product, building, or system over its entire life cycle, from raw material extraction to disposal. This allows architects to consider the environmental impact of their designs and make informed decisions that minimize harm to the environment (Fnais et al., 2022). Circular design strategies, on the other hand, promote the idea of closed-loop systems, where waste is reduced

and resources are conserved. These strategies encourage architects to design buildings that can be easily disassembled, recycled, and repurposed, reducing the amount of waste generated and contributing to a more sustainable future (Attia & Al-Obaidy, 2021).

However, incorporating these principles into architecture education can be challenging for several reasons. Firstly, the complexity of building LCA, as it involves multiple interrelated parameters, makes it difficult for students to base decisions on during their design process. The difficulty of LCA application is related to various areas. Performing LCA requires a significant amount of data and expertise, including well-defined building plans, inventory assessment of materials, and knowledge of production and demolition processes. The environmental impact assessment also faces difficulties such as non-standardized material production and limited access to information about environmental impacts of the production and manufacturing of construction materials plus the actual process of construction and demolition (Ramesh, Prakash, & Shukla, 2012). Furthermore, embodied energy and equivalent carbon emissions can vary due to the energy mix, transformation processes, efficiency of the industrial and economic system of the country, and the variability of these factors over time (Sartori & Hestnes, 2007), making it challenging to make informed decisions. Previous studies on life cycle energy requirements have also shown that a material's performance can vary in different situations. It is crucial to make decisions from a life cycle perspective that does not worsen the overall environmental impact, even if they reduce it for one stage. Previous studies on life cycle energy requirements (Crawford, 2011; Utama & Gheewala, 2009) have shown that the performance of a material or assembly can vary based on the context in which it is used. For example, a material with low initial embodied energy may not necessarily have low life cycle energy. The lack of generalizable design principles and the use of different assumptions, databases, and analysis methods in LCA studies further complicate the application of LCA in architecture education.

LCA and circular design require a multidisciplinary approach, involving expertise from fields such as engineering, materials science, and environmental science. This can make it difficult for architecture schools to provide the necessary training and resources to students. Despite these challenges, the benefits of incorporating LCA and circular design into architecture education far outweigh the difficulties, as they equip future architects with the knowledge and skills necessary to create a more sustainable future.

3. How can AI be utilized to streamline the implementation of Life Cycle Assessment and Circular design techniques in architecture education?

Large Language Models (LLMs) are powerful machine-learning models that have been trained on vast amounts of text data, allowing them to understand and generate human-like language (Devlin, Chang, Lee, & Toutanova, 2018). They have many applications, including

data retrieval and educational use cases. In data retrieval, LLMs can be used to extract information from large databases, such as medical records or legal documents. They can also assist in chatbots, customer service, and search engines by understanding natural language queries and providing relevant responses. In education, LLMs can facilitate personalized learning experiences by generating customized quizzes, exercises, and feedback based on student responses (Brown et al., 2020). However, despite the significant potential of these AI models there is no application report in the field of architecture education. AI has the potential to revolutionize the way LCA and circular design techniques are implemented in architecture education. These techniques play a critical role in ensuring that buildings are designed and constructed in a sustainable and environmentally responsible manner. However, their implementation can be complex, time-consuming, and challenging for students. In this article, several ways that AI can be utilized to streamline the implementation of LCA and circular design techniques in architecture education are discussed (Gomes et al., 2022; Ji, Lee, & Yi, 2021).

Automated Data Collection: LCA requires a significant amount of data collection and analysis, including information on embodied energy, carbon emissions, and other environmental impacts of building materials, products, and systems. AI can automate this process by collecting data from various sources and processing it in a way that is fast and accurate. This can reduce the time and effort required for manual data collection, allowing students to focus on the analysis and interpretation of the results.

Predictive Modelling: AI algorithms can be trained to predict the environmental impact of different building materials, systems, and assemblies. This can help students to make informed decisions about the materials and systems they use in their designs, based on the predicted environmental impact. Predictive modelling can also be used to optimize the design based on specific sustainability and environmental criteria, allowing students to find the most sustainable and circular design solutions.

Optimization: Optimization is a critical component of circular design and LCA. AI can be used to optimize the design based on specific sustainability and environmental criteria, such as embodied energy, carbon emissions, and waste reduction. AI can be used to optimize product designs for circularity, by identifying opportunities for materials reuse, repair, and recycling This can help students to find the most sustainable and circular design solutions and understand the trade-offs involved in different design decisions.

Visualization: The results of LCA and circular design analysis can be complex and difficult to interpret for students. AI can be used to visualize and communicate these results in a way that is accessible and intuitive, improving students' understanding of the concepts. This can include visualizations of the environmental impact of different building materials, systems, and assemblies, as well as visualizations of the circular design process and its outcomes

(Abioye et al., 2021; E. Gilner, A. Galuszka, & T. Grychowski, 2019; Ji et al., 2021; Oluleye, Chan, & Antwi-Afari, 2023; Xue et al., 2021).

In conclusion, AI has the potential to revolutionize the way LCA and circular design techniques are implemented in architecture education. By automating data collection, enabling predictive modelling, optimizing designs, and improving visualization, AI can make these techniques more efficient, effective, and accessible for students. As a result, architecture students will be better equipped to design and construct buildings that are sustainable and environmentally responsible.

4. Methodology: Leveraging AI to instruct architecture students on circular design techniques and LCA

The methodology of this study leverages a theoretical model to examine the potential of AI in educating architecture students on circular design techniques and LCA. The research process involves analysing the current challenges and solutions in this field, exploring various perspectives, and providing explanations, predictions, and proposed solutions.

To achieve this, the study aims to:

- Minimize data requirements and identify the most effective parameters with the greatest potential for impact
- Define a system boundary that is specific to each building, limiting the criteria for LCA
- Offer recommendations and rules of thumb for environmentally friendly design decisions based on the results of previous LCA studies.

In this study, a Knowledge-based System (KBS) was utilized to introduce a method for application of simplified LCA by architecture students. KBS is a computer system that leverages various forms of AI for problem-solving across different domains. It consists of a database of expert knowledge that is tailored for specific queries, along with learning and justifications capabilities. The system provides data and information from multiple sources and is designed to support human decision-making through the use of knowledge-based techniques. To simplify usage of the KBS system for students we propose to integrate a Large Language Model (LLM) such as chat-gpt3-turbo (Ouyang et al., 2022) with KBS. The LLM model can assist in processing student queries and questions in natural language, which can be challenging for traditional KBSs. By leveraging the LLM's ability to understand context and generate relevant responses, the KBS can provide more accurate and tailored results to student queries which have always proven to be very difficult and time consuming for the students to grasp. several implementations for such a system have been proposed (Izacard & Grave, 2020; Izacard et al., 2022; Khattab et al., 2022). In this study we will adapt the method proposed by (Yao et al., 2022).

The tool is structured into three main parts: inputs, system functions, and outputs. The inputs section requires essential information about the building to be inputted, such as climate, location, building type, and building lifetime, to investigate the most effective parameters on the building's life cycle environmental performance (Tabrizi & Brambilla, 2019). System functions are made up of a basic tool that utilizes KBS, which contains rules specific to the domain. This enables the system to generate outputs based on the user's inputs, helping students make more environmentally conscious decisions at the early stages of the design process with minimal time, effort, and cost.

Outputs from the system provide recommendations for design and material selection decisions for the building's envelope structure, which are expected to minimise the building's life cycle environmental impact. These recommendations are generated in different groups like one for window design and the other for solid envelope design, based on the specific conditions of each building that the user inputs into the system (Figure 1).

In conclusion, the KBS-designed LCA method serves as a valuable resource for architecture students, as it simplifies the process of understanding the complexities of circular design techniques and LCA. The tool's outputs provide a foundation for thinking through problems and understanding the life cycle of a building, from cradle to cradle.
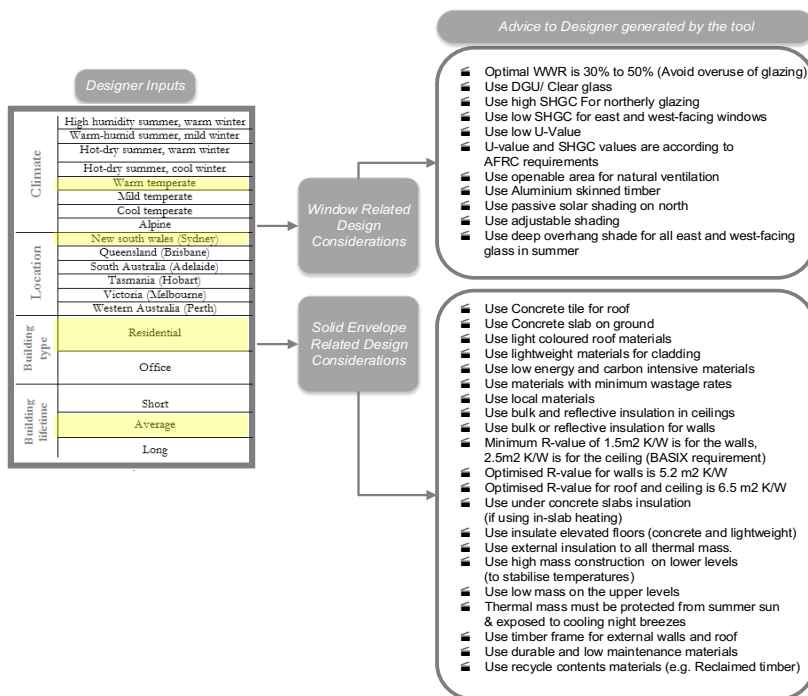

Figure 1. Inputs and outputs sample for a hypothetical case study in Sydney. Source: (Tabrizi & Brambilla, 2019).

5. Concusions and future research

The research aims to shed light on how AI can facilitate the integration of cradle-to-cradle thinking into the design process of architecture students. The study aims to enhance the instruction of LCA to architecture students by combining the standard LCA framework with the power of AI. The research highlights the importance of considering sustainability in architecture education and the challenges faced in teaching these concepts to students. The use of AI in this context can simplify the process of sustainability education and provide a quick early analysis of the building's life cycle environmental performance. The method aims to overcome the difficulties faced by architecture students in understanding and applying LCA, and provides a means for them to perform assessments and make informed decisions on their designs. The output of this method helps students understand the environmental impact of their design decisions and supports them in optimizing environmental performance through multiple dimensions while considering the specific conditions of each building. The immediate next step that this research team is going to take is to apply this theoretical model on a real case study to investigate the applicability of this proposed model.

Future research will progress to the user studies and implementation of the proposed method to the teaching and learning process. This stage of the project will systematically evaluate the benefits and limitations when applied in the context of higher architectural education for architecture. A series of 1–2-day workshops will be run at the University of Sydney – School of Architecture, Design and Planning targeting architecture students as a test population.

A follow up offshoot of this study will aim to evaluate the benefits and implementation methods of educational AI for conceptual design in architecture. This AI application will focus on qualitative aspects of design thinking to accompany quantitative assessments of the proposed AI for LCA . This holistic approach of using AI for both quantitative and qualitative aspects of design solutions will allow to create a more informed feedback loop, allowing learners to assess multiple parameters at the same time.

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