International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Sustainable Material Choice for Apartment Building Construction: A Life Cycle Assessment Based on BIM and Life Cycle Metrics Tool

[1]Jahnavi Adduri, [2]Ch Chandini, [3]A Santosh Kumar, [4]K Vardhan, [5]K Sandeep

[1,2,3,4,5]GMR Institute of Technology

DOI: https://doi.org/10.55248/gengpi.2023.4.33185

ABSTRACT

The study aims at evaluating the sustainable material choices for apartment building construction utilising a Life Cycle Assessment (LCA) based on Building Information Modelling (BIM) and a Life Cycle Metrics Tool. The study focuses on determining the environmental implications of various material options, including as steel, concrete, wood, and masonry. It considers the environmental impact of materials at every stage of their life cycle. The study technique entails utilising BIM to produce a virtual model of the building, which is then utilised to generate a Life Cycle Metrics tool to analyse the life cycle of the building components. The Life Cycle Matrix tool compares the environmental effect of various materials over the course of a building's life cycle.

INTRODUCTION

In the current worldwide landscape, the architecture, engineering, and construction (AEC) business has been labelled as the greatest carbon emitter due to its renowned detrimental influence on the environment throughout the years. As a result, awareness about sustainability and reducing the environmental effect of building is growing, particularly throughout the project phase of development. Sustainable Material Choice for Apartment Building Construction is a critical consideration in today's world, where there is an increasing demand for eco-friendly and energy-efficient building solutions. Researches have worked to examine alternate materials, technologies and design concepts that are less harmful to the environment throughout the previous decade.

Building information modelling (BIM) is defined as a technique that includes policies, methods, and technology for managing critical building design and project data in digital format throughout a building's life cycle. The amount of information of a model is determined by its purpose and the type of analysis it is intended to do. Because the BIM model has accurate material attributes and permits multidisciplinary information to be layered on a single model, it has the potential to provide an efficient environmental performance analysis and sustainability enhancement evaluations.

LCA is acknowledged as a method for evaluating all life cycle phases of a product through an interactive approach. It examines the material resources, processes, greenhouse gas (GHG) emissions, and energy inputs/outputs involved across the whole product life cycle. The environmental performance of construction should be evaluated during the project phase since this is when improvements may be made to minimise needless consequences. Therefore, not only cost and time can be reduced in this phase but also environmental impacts. A Life Cycle Assessment (LCA) based on Building Information Modelling (BIM) and Life Cycle Metrics Tool is a powerful tool that helps in evaluating the environmental performance of different materials throughout their life cycle.

Therefore, it is essential to explore ways to reduce the negative impact of the construction industry on the environment. The research paper argues that sustainable material choices can significantly reduce the environmental impact of construction. The research investigates the life cycle of various construction materials, from extraction through disposal, to estimate their environmental effect. BIM and the Life Cycle Metrics Tool are used to construct a digital model of the building and to analyse the environmental effect of various building materials. The paper concludes that sustainable material choices such as reclaimed bricks, cement free mortar and recycled steel reinforcement, can significantly reduce the environmental impact of construction.

LITERATURE REVIEW

LCA and BIM: Integrated assessment and visualization of building elements' embodied impacts for design guidance in early stages

This paper shows the results when there is a link between the BIM model from Autodesk Revit and LCI from building element library. The combination of LCA with BIM can give a full assessment of the environmental implications of architectural features during the early phases of design. The visualization of embodied affects can help designers make educated decisions about materials and procedures. Case studies have demonstrated that combining LCA and BIM may help reduce the embodied carbon of buildings. Future study might look towards integrating LCA and BIM with additional sustainability criteria, including as social and economic consequences.

BIM-Based LCA throughout the design process: A Dynamic Approach

The BIM-Based LCA (Life Cycle Assessment) method is a dynamic and effective way for improving the sustainability of building projects throughout the design process. By combining BIM (Building Information Modelling) with LCA techniques, this methodology enables designers and decision-makers to assess the environmental consequences of various design possibilities and make educated decisions that decrease the building's environmental footprint. This technique also enables designers to evaluate multiple design possibilities at various phases of the design process, allowing them to find the most sustainable design solutions early on. It is a dynamic technique that allows for the study of many design possibilities and helps designers to make educated decisions that lessen the environmental effect of the building.

Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP

This work presents an innovative proposal for integrating LCSA, BIM and MCDA to determine the most sustainable choice of materials for construction projects. In the case study which is presented in this paper, four different material lists were tested for the same building to decide which alternative would be the most sustainable. Among the selected alternatives, a variation of up to 59.97% in global warming potential, a 16.11% variation in the energy cost for lighting and 22.80% variation in the energy cost for HVAC were found through the LCSA-BIM-MCDA integration.

A systematic review of BIM usage for life cycle impact assessment

This work presents Systematic Literature Review (SLR) related to the use of BIM to assist in building life cycle impact assessment, emphasizing carbon emissions. Several aspects of this literature review show the need to develop automated processes for LCA of buildings during project's development phase.The BIM–LCA technique still has great development potential, especially when it comes to the possibility of integrating other information and communication technologies.The use of BIM technology enhances the accuracy and efficiency of the assessment, while Fuzzy-AHP provides a systematic approach for evaluating the relative importance of various sustainability criteria. Overall, the LCSA framework based on BIM and Fuzzy-AHP provides a powerful tool for promoting sustainable material choices in construction projects and contributing to the development of a more sustainable built environment.

The coupling of BIM and LCA – Challenges identified through case study implementation

This study is done to have clarification about the structure and completeness as well as granularity of a building model before deciding for the assessment workflow and tools used. The study discusses the potentials, challenges and learnings from two BIM-LCA case studies. The following are the challenges of BIM-LCA implementation: Incompleteness of the BIM model, Different Levels of Development (LOD) of the various building element and different scenarios are applied on different levels.

BIM Integrated LCA for Promoting Circular Economy towards Sustainable Construction: An Analytical Review

The study demonstrated that integrating BIM with LCA can provide significant benefits in evaluating the entire life cycle of a building, such as the quantification of materials with different alternatives, the selection of sustainable materials early in the design phase, and faster and more accurate quantification and evaluation. By critically examining recent literature, this study sought to uncover the consequences, concerns, contributions, and limitations of BIM integrated LCA and CE adoption in the industry.

An integrated approach of BIM-enabled LCA and energy simulation: The optimized solution towards sustainable development

The study looked at the embodied energy of the items, covering the production, transportation, and constructing phases. It has been shown that a small increase in embodied energy (2.8%) at the production stage for insulation goods can save up to 76% of total energy use during operation. Furthermore, the examination found that the influence of insulating materials during the manufacturing stage was substantially larger than that of other materials. Insulation accounts for 4% of total carbon emissions and 7% of primary energy demand throughout the life cycle, but accounting for just 1% of total mass.

METHODOLOGY

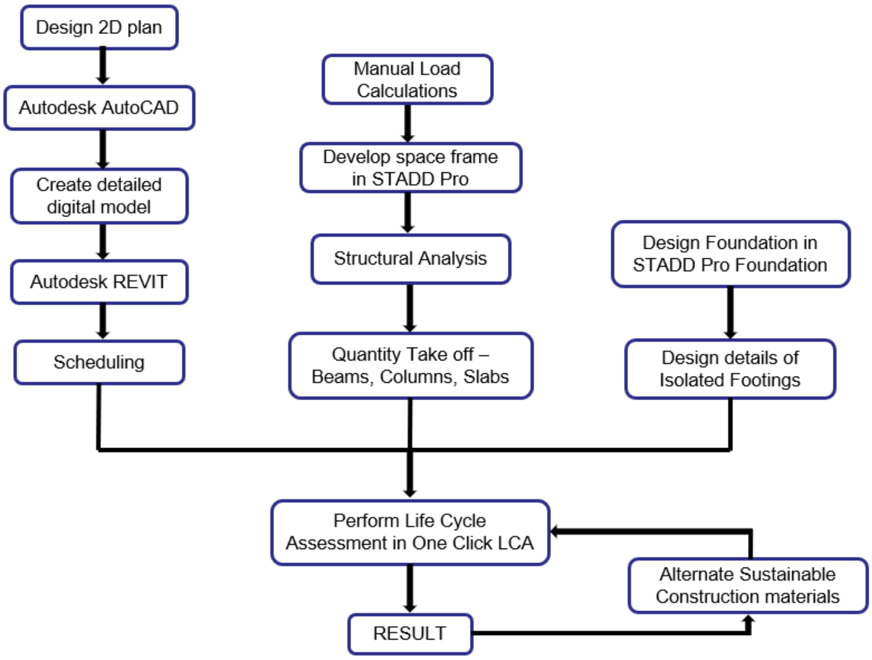


Fig. 1 Methodology flowchart for sustainable material selection

The first step is to design a 2D plan and develop 3D model of apartment building in BIM softwares. The detailed digital model should include all the structural and non-structural components of the building such as foundation, columns, beams, slabs, doors, windows and other building systems.

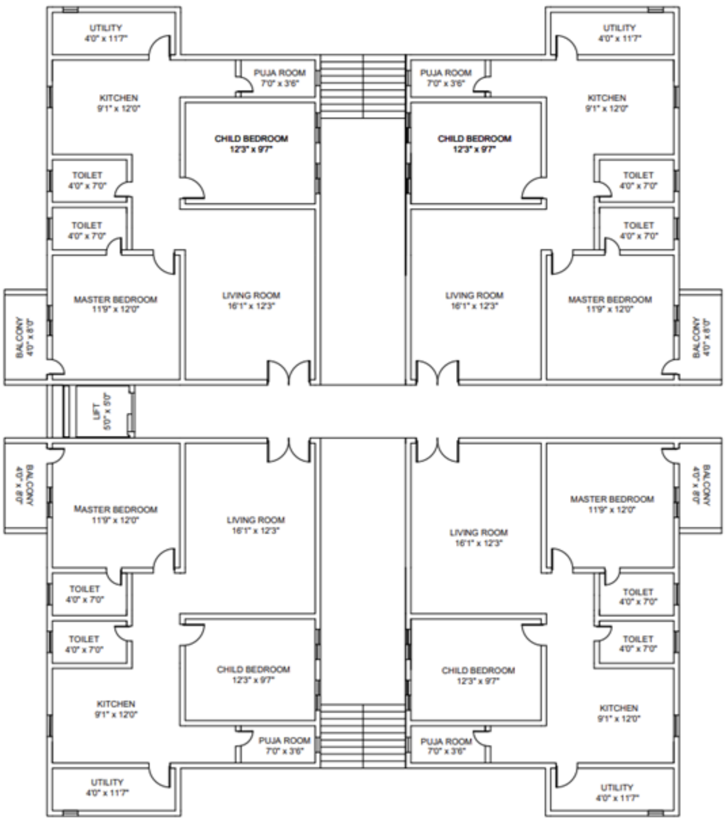


Figure 2 2D plan of G+4 Apartment building

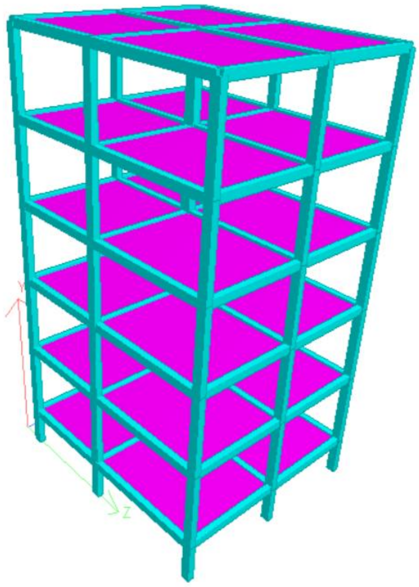


Figure 3 3D Rendered View of Apartment building in STADD.Pro

The next step is to use STADD.Pro to do a load analysis and obtain quantity take-offs from the outcomes. Loads are computed manually and applied to all structural components in STADD.Pro for this purpose. A space frame is developed in STADD.Pro. This is accomplished by selecting the suitable tools for constructing the walls, slabs, columns, beams, and other structural components. The geometry and layout of the building should be appropriately represented in the model.

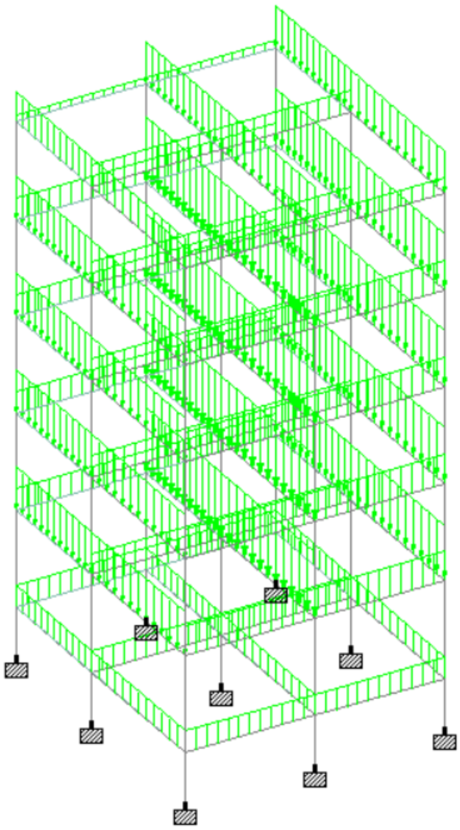


Figure 4 Load application details for structural members

Design the structural elements like foundation using STADD.foundation and slab using manual calculations. Design of beams and columns is obtained directly after performing analysis in STADD Pro. Then identify the materials used in the building construction. This information may be retrieved from the building designs, specifications, and schedules. After the materials have been identified, a Life Cycle Matrix tool may be created to analyse the materials' environmental effect. The Life Cycle Matrix tool should take into account the whole life cycle of construction materials, including manufacture, transportation, installation, usage, and disposal. This tool may be used to evaluate each material's environmental effect in terms of energy consumption, greenhouse gas emissions, water usage, and other environmental factors. The study findings may be used to select materials with the lowest environmental effect as well as sustainable alternatives.

RESULTS AND DISCUSSIONS

To carry out load analysis, STADD.Pro on an apartment building is used and OneClick LCA software may be used to undertake life cycle assessment (LCA) of the structure. LCA is a process for assessing the environmental effect of a product or system across its full life cycle, from raw material extraction to manufacture, usage, and disposal. Following the load study, automated beam and column designs are developed. The amount take-offs are also acquired.

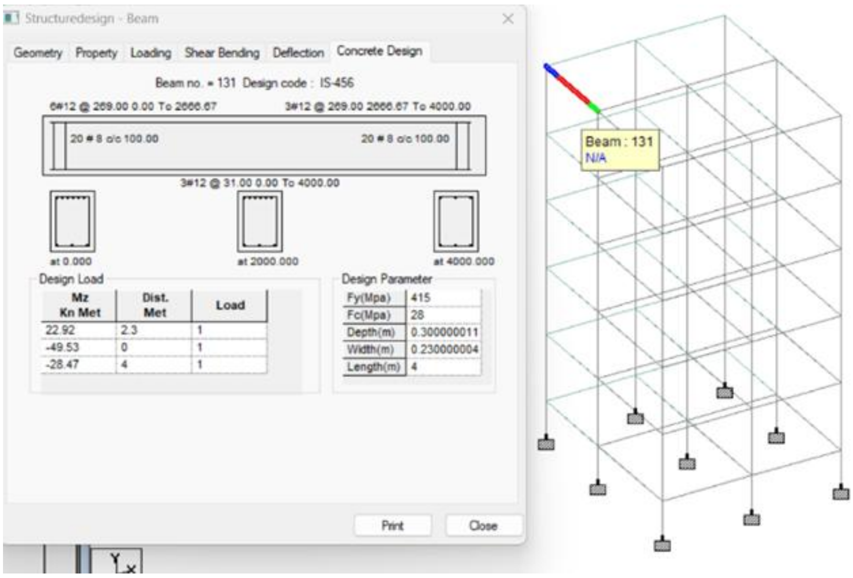


Figure 5 Beam Design

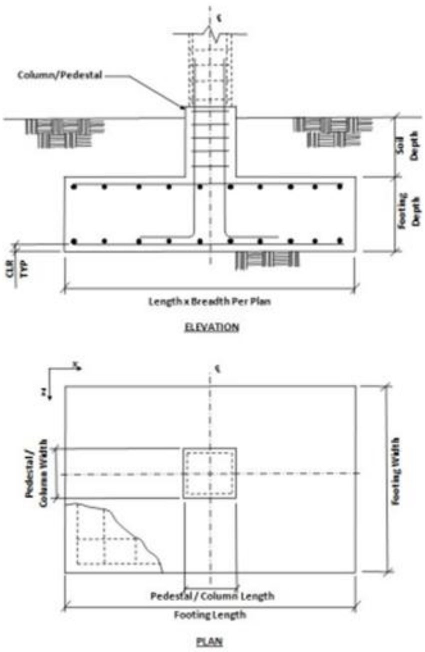


Figure 6(a) Foundation design

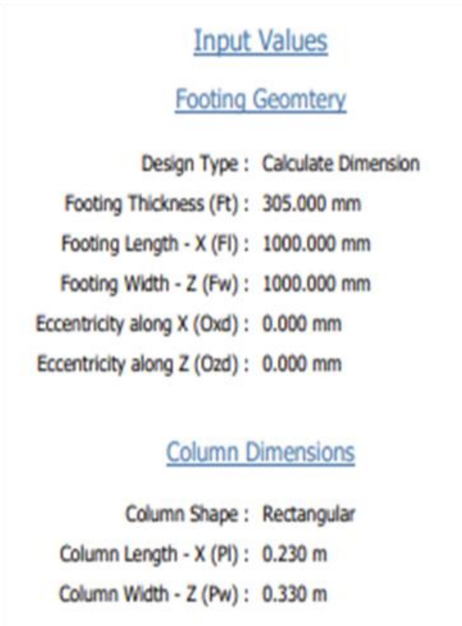
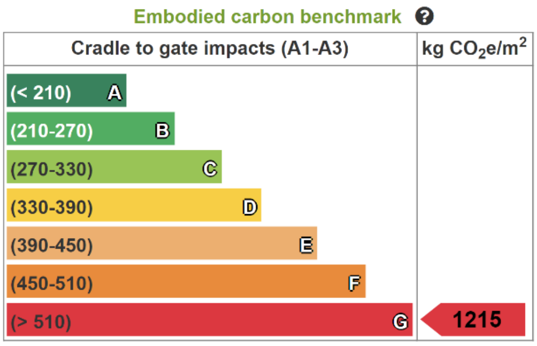


Figure 6(b) Footing and column dimensions

Considering them as inputs, life cycle assessment is performed in OneClick LCA software. This tool assists designers and builders in determining a building's carbon footprint by assessing the embodied carbon of the materials used in construction. The carbon emissions connected with the manufacture and transportation of construction materials are referred to as embodied carbon. Moreover, OneClick LCA may be used to improve building design in order to decrease energy usage during the operational phase, which leads to lower carbon emissions. We have four sets of alternatives to perform LCA.

Case 1: The first alternative of building materials is Ready-mix concrete (RMC) with 10% fly ash content in cement, steel reinforcement with 0% recycled content, ordinary clay bricks and cementitious mortar for masonry work. After performing LCA, it was shown that 437 tonnes of CO2 is released.



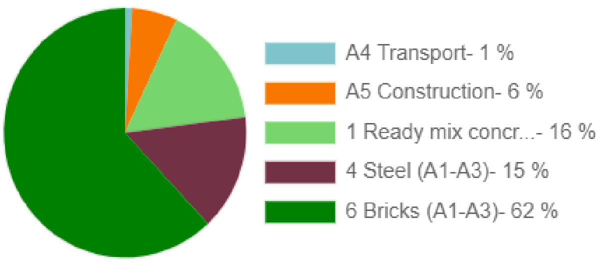
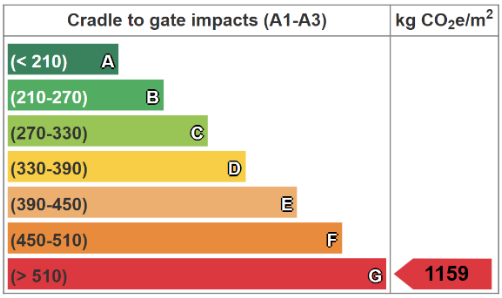


Figure 7(a) Embodied carbon benchmark **Figure 7(b)** Global warming – life cycle stages

Case 2: The first alternative of building materials is Ready-mix concrete (RMC) with 20% fly ash content in cement, steel reinforcement with 15% recycled content, ordinary clay bricks and cement free mortar for masonry work. After performing LCA, it was shown that 417 tonnes of CO2 is released.



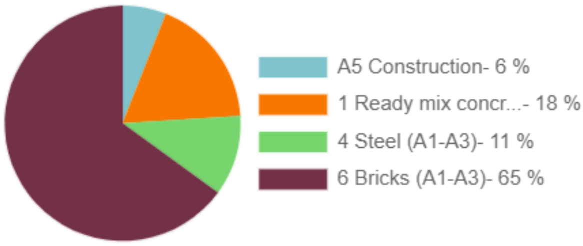
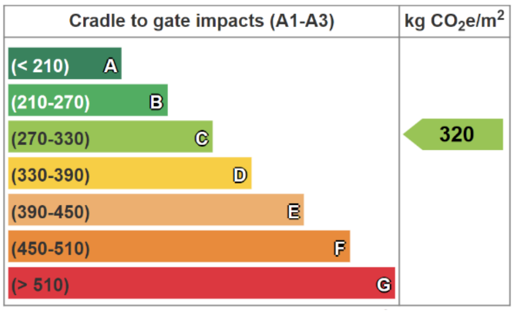


Figure 8(a) Embodied carbon benchmark **Figure 8(b)** Global warming – life cycle stages

Case 3: The first alternative of building materials is Ready-mix concrete (RMC) with 30% fly ash content in cement, steel reinforcement with 60% recycled content, reclaimed clay bricks and cement free mortar for masonry work. After performing LCA, it was shown that 115 tonnes of CO2 is released.



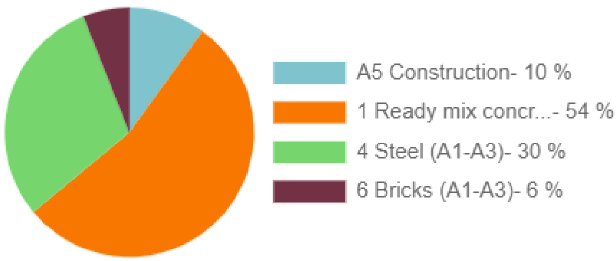
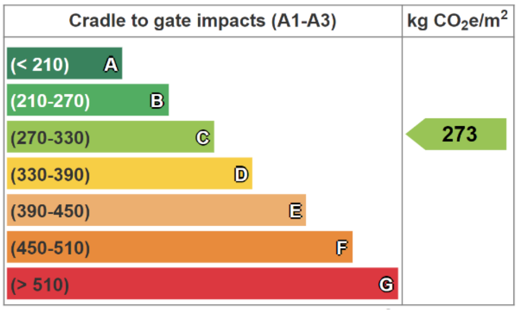


Figure 9(a) Embodied carbon benchmark

Figure 9(b) Global warming – life cycle stages

Case 4: The first alternative of building materials is Ready-mix concrete (RMC) with 30% fly ash content in cement, steel reinforcement with 100% recycled content, reclaimed clay bricks and cement free mortar for masonry work. After performing LCA, it was shown that 98 tonnes of CO2 is released.



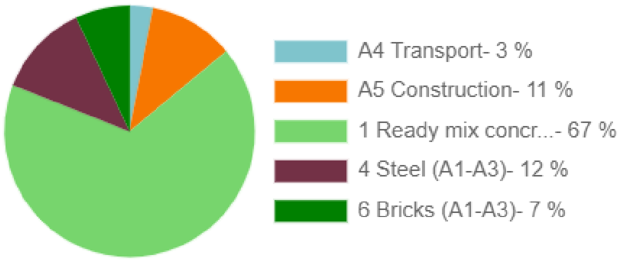


Figure 10(a) Embodied carbon benchmark **Figure 10(b)** Global warming – life cycle stages

Finally, the fourth alternative with 30% fly ash content in ready-mix concrete (RMC), 100% recycled steel reinforcement, reclaimed bricks, cement free mortar and wooden doors with triple gazed and aluminium cladding are found to be sustainable compared to the other alternatives because huge amount of reduction in carbon emissions is observed.

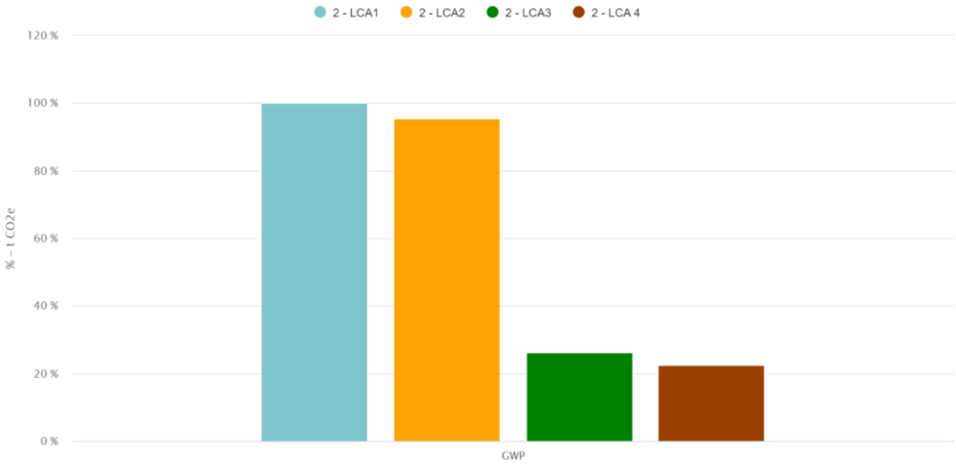


Figure 11 Comparison of four alternatives tested via Life Cycle Metrics tool

The results of the analysis may depend on a variety of factors, including the specific materials and designs being compared, the location of the building, and the assumptions made in the life cycle assessment. However, some general trends and conclusions may emerge from the analysis, such as the relative environmental benefits of using recycled or renewable materials, or the importance of considering energy efficiency and emissions reductions throughout the building's life cycle.

CONCLUSION

The use of BIM and the Life Cycle Matrix tool to select sustainable materials for apartment building construction is an important step in reducing the environmental effect of building construction. BIM allows architects, engineers, and building designers to create virtual models of structures, allowing them to optimise building design and examine the environmental effect of building materials. The Life Cycle Matrix programme analyses the environmental impact of construction materials during their full life cycle, allowing for the selection of sustainable material alternatives with the lowest environmental impact. The study discovered that the choice of construction materials has a considerable influence on the building's environmental and economic performance across its life cycle. By taking into account the environmental consequences of building materials at each step of their life cycle, from raw material extraction through end-of-life disposal, educated decisions may be made to lessen the total environmental impact of the project. By integrating LCA data into these tools, it is possible to evaluate the environmental impact of different material options in real-time and make informed decisions on material selection.

In conclusion, the study underlines the need of applying a comprehensive and integrated approach to sustainable material selection for apartment building construction. By evaluating the whole life cycle of building materials and employing technologies such as BIM and LCMT, it is feasible to make more sustainable decisions that benefit both the environment and the economy.

Acknowledgment

We would like to express our gratitude to Dr. G. Ganesh Prabhu, Head of the department, Department of Civil Engineering at GMR Institute of Technology in Rajam-532127, Andhra Pradesh, for his assistance throughout the project.

REFERENCES

[1] Amor, B., & Vachon, S. (2016). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-design improvement potential. Journal of Cleaner Production, 113, 667-676.

[2] Mokhlesian, M., Ghorbani, R., &Alavi, S. (2019). Life cycle assessment of building materials: A review. Journal of Building Engineering, 26, 100857.

[3] Sartori, I., &Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. Energy and Buildings, 39(3), 249-257.

[4] Soust-Verdaguer, B., & Sánchez-Soto, P. J. (2019). Comparative life cycle assessment of structural systems for a residential building. Journal of Cleaner Production, 212, 60-73.

[5] Wang, J., Shen, L., & Zhang, Y. (2018). Life cycle assessment of wood-concrete composite floor for residential building. Journal of Cleaner Production, 196, 777-785.

[6] Shafiq, N. and Gardezi, S.S.S. (2015), "Reduction of embodied CO2 emissions from conventional single Storey house in Malaysia by recycled materials using building information modelling (BIM)", Advances in Environment Biology, Vol. 9 No. 1, pp. 17-21.

[7] Y.H. Dong, S.T. Ng, A social life cycle assessment model for building construction in Hong Kong, Int. J. Life Cycle Assess. 20 (2015) 1166–1180

[8] M. Rock, ¨ A. Hollberg, G. Habert, A. Passer, LCA and BIM: visualization of environmental potentials in building construction at early design stages, Build. Environ. 140 (2018) 153–161

[9] C. Llatas, B. Soust-Verdaguer, A. Passer, Implementing life cycle sustainability assessment during design stages in building information modelling: from systematic literature review to a methodological approach, Build. Environ. 182 (2020)

[10] M. Najjar, K. Figueiredo, M. Palumbo, A. Haddad, Integration of BIM and LCA: evaluating the environmental impacts of building materials at an early stage of designing a typical office building, J. Build. Eng. 14 (2017) 115–126.

[11] Dupuis, M., April, A., Lesage, P. and Forgues, D. (2017), "Method to enable LCA analysis through each level of development of a BIM model", Procedia Engineering, Vol. 196, pp. 857-863.