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Parametric Analysis of Building Materials Life Cycle Assessment Using Bim

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ABSTRACT:

In this study, two effective techniques—BIM and LCA—will be highlighted. In the context of sustainability, such techniques can be quite helpful. Utilizing a Life Cycle Assessment (LCA) based on Building Information Modelling (BIM) and a Life Cycle Metrics Tool, the study attempts to evaluate the sustainable material selections for apartment building construction. 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 utilizing BIM to produce a virtual model of the building. STAAD Pro is used to evaluate the research and design of a apartment development. Planning is done in AutoCAD, load calculations are done manually, and the structure is then analyzed in STAAD Pro. STAAD Pro is one of the leading software's for the design of structures. The structural engineering software tool STAAD Pro is used to analyze and design a wide range of different types of structures utilizing the Limit state design philosophy in accordance with IS 456:2000. Calculations are made and applied to the structure for the dead load, imposed load, and wind load. Throughout the life cycle of a building, the Life Cycle Matrix tool compares the environmental impact of various materials. We suggest a workflow that tests a large range of potential construction solutions using conceptual BIM models and visual scripting. Using the information from this study, architects, engineers, and building designers will be better equipped to choose environmentally friendly building materials.

Keywords: Building Information Modelling (BIM), Life Cycle Assessment (LCA), Carbon emissions.

1. Introduction

The construction industry plays a pivotal role in global economic development and urbanization, but it is also a significant contributor to environmental degradation. Building materials, in particular, have a substantial impact on the environment throughout their life cycle, from extraction and production to construction, use, and eventual disposal. In response to the growing awareness of environmental concerns, the concept of Life Cycle Assessment (LCA) has emerged as a crucial tool for evaluating the environmental footprint of building materials and structures. Integrating Building Information Modeling (BIM) into LCA processes has become increasingly important, as it allows for more accurate and efficient parametric analysis of building materials' life cycles.

Life Cycle Assessment (LCA) is a systematic methodology used to quantify the environmental impacts of a product, process, or system throughout its entire life cycle. It takes into account various environmental factors, such as resource consumption, energy use, emissions, and waste generation, to assess the overall sustainability of a product or construction project. LCA is divided into several stages, including goal and scope definition, inventory analysis, impact assessment, and interpretation of results. Traditionally, conducting LCA has been a time-consuming and resource-intensive process, but the integration of BIM technology has revolutionized the way LCA is performed.

Building Information Modeling (BIM) is a digital representation of a building's physical and functional characteristics, providing a 3D model enriched with data about the project's geometry, materials, and other attributes. BIM facilitates collaboration among stakeholders, improves project visualization, and enhances project management. However, its integration with LCA adds an additional layer of value by enabling parametric analysis of building materials' life cycles.

Parametric analysis in the context of BIM and LCA involves manipulating design parameters, such as materials, insulation, or structural systems, to assess their direct impact on a building's environmental performance. This iterative process allows designers, architects, and engineers to make informed decisions that minimize environmental impacts without compromising functionality or aesthetics. With parametric analysis, stakeholders can explore various scenarios, identify optimal solutions, and fine-tune designs to achieve sustainability goals.

The integration of BIM and LCA enables a seamless flow of information throughout the building's life cycle. Initially, BIM provides the necessary data on building materials, quantities, and specifications. This information is then fed into LCA software, which calculates the environmental impacts based on the data inputs and predefined impact categories. Parametric analysis allows users to experiment with different design choices, instantly visualizing the corresponding changes in environmental performance metrics.

The benefits of using BIM for parametric analysis of building materials' life cycle assessment are numerous. First, it streamlines the LCA process, reducing the time and effort required for data collection and analysis. Second, it promotes collaboration among project stakeholders, fostering a holistic approach to sustainable design. Third, it allows for more accurate and granular assessments, taking into account specific project conditions and design choices. Fourth, it facilitates decision-making by providing real-time feedback on the environmental consequences of design decisions.

In conclusion, the integration of Building Information Modeling (BIM) and Life Cycle Assessment (LCA) represents a significant advancement in sustainable construction practices. Parametric analysis enabled by BIM technology allows for a more comprehensive evaluation of building materials' environmental impacts, enabling designers and stakeholders to make informed decisions that promote sustainability while meeting project goals. This approach not only contributes to reducing the environmental footprint of the construction industry but also enhances the overall quality and efficiency of building design and construction processes. As environmental concerns continue to grow, the use of BIM for parametric LCA analysis is expected to become a standard practice in the construction industry.

2. Literature Review

S. No.	Author	Title	Year	Methodology adopted	Observation
1	Martin Rock,Alexander Hollberg	LCA and BIM Integrated assessment and visualization of buildings elements embodied impact for design guidance in early stages	2018	The methodology used in the journal paper "LCA and BIM Integrated Assessment and Visualization of Buildings Elements Embodied Impact for Design Guidance in Early Stages" included developing a BIM model, material selection, life cycle assessment, integration of BIM and LCA, visualization of results, design guidance, and sensitivity analysis. The technique enabled the authors to assess the environmental impact of building materials early in the design phase and give design suggestions for lowering the project's environmental impact. The combination of BIM and LCA offers architects and designers with a valuable tool for making educated decisions regarding sustainable building design.	This paper shows the results when there is a link between the BIM model from Autodesk Revit and LCI from building element library. This shows that it is possibleto accomplish an integration of LCA in BIM when using a common granularity in both, LCA data and BIM-based bill of quantities as well as specifying a common naming convention.Furthermore, this approach allows to havea BIM-integrated calculation of embodied impacts for different design and construction options in early design stages.
2	Gianluca Genova, Basler and Hoffman	BIM-Based LCA throughout the design process: A Dynamic Approach	2019	The methodology used in the paper "BIMBased LCA Throughout the Design Process: A Dynamic Approach" included the definition of LCA scope, the development of a BIM model, the integration of LCA analysis, dynamic LCA analysis, the evaluation of LCA results, the optimization of design	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

				decisions, and the communication of LCA results. The paper presents a valuable technique for enabling dynamic LCA analysis during the design process, which can drive sustainable design decisions and enhance building environmental performance.	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.
3	Karoline Figureiredo, Rodrigo Pierott, Ahmed W.A. Hammad	Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP	2021	The methodology adopted in the study "Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP" involves the following steps: The first step is to define the problem statement and objectives of the study. In this case, the objective is to develop a framework for selecting sustainable materials for construction projects based on life cycle sustainability assessment (LCSA) using Building Information Modelling (BIM) and Fuzzy Analytic Hierarchy Process (Fuzzy-AHP).The second step is to conduct a comprehensive literature review to identify relevant studies and frameworks related to sustainable material selection for construction projects, LCSA, BIM, and Fuzzy-AHP.The third step is to develop a framework for sustainable material selection using BIM and Fuzzy-AHP. The framework consists of four main stages: data collection, impact assessment, decision-making, and sensitivity	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.

				analysis.The fourth step is to apply the developed framework to a case study project to evaluate its effectiveness and validate its results.The fifth step is to analyse the results of the case study and compare them with other studies to demonstrate the effectiveness of the developed framework and to draw conclusions.	
4	Julianna Crippa, Aline M.F. Araujo, DiogoBeme	A systematic review of BIM usage for life cycle impact assessment	2020	The methodology used in the journal paper "A Systematic Review of BIM Usage for Life Cycle Impact Assessment" included a systematic search of academic databases, study selection based on predetermined criteria, data extraction, quality assessment, data analysis and synthesis, and gap analysis. The systematic review gives a complete overview of the present status of BIM utilization for LCIA and highlights gaps and limitations in the literature, which can guide future research in this field.	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.
5	M.Rock, A. Passer, D.Ramon	The coupling of BIM and LCA – Challenges identified through case study implementation	2019	The methodology used in the paper "The Coupling of BIM and LCA: Challenges Identification through Case Study Implementation" included the selection of a case study building, development of BIM and LCA models, coupling of BIM and LCA models, data collection and	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

				analysis, challenge identification and solution proposal, and evaluation of proposed solutions. The study gives useful insights into the constraints and limitations of coupling BIM and LCA, as well as solutions to these challenges.	implementation: Incompleteness of the BIM model, Different Levels of Development (LOD) of the various building element and different scenarios are applied on different levels.
6	Kai Xue, Md. Uzzal Hossain, Meng Liu	BIM Integrated LCA for Promoting Circular Economy towards Sustainable Construction: An Analytical Review	2021	The methodology adopted in this journal paper involves the following steps: The first step is to identify the project goals and objectives. This includes defining the scope of the project, identifying the stakeholders, and establishing the metrics that will be used to evaluate the project's performance.The second step is to develop a Building Information Model (BIM) of the project.The next step is to identify the materials that will be used in the construction process and their sources.Once the materials have been identified, the next step is to analyse their life cycle impacts. This includes evaluating the environmental impact of the materials throughout their life cycle, from raw material extraction to disposal.	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.
7	Patrick Bynum; Raja R. A. Issa, F. ASCE; and Svetlana Olbina, A.M.	How designers and builders feel aboutusing BIM for environmentally friendly design andconstructio n	2013	To ascertain the current trends of BIM application generally as well as its use as a tool in sustainable design and construction, a survey was created and distributed via the Internet.	The purpose of this study is to find out how designers and builders feel about using BIM for environmentally friendly design and construction. To ascertain the current trends of BIM application generally as well as its use as a tool in sustainable design and construction, a survey was created and distributed via the Internet. According to the survey's results, majority (89%) of the 123 respondents used BIM, and more than half (51%) of them had been doing so for more than three years.

					Although the majority of respondents (63%) strongly agreed that sustainable design and construction methods were vital inside their companies, most still thought that project coordination and visualization were more crucial than sustainability as a key application of BIM.
8	Stefan Lueddeckens, Peter Saling, Edeltraud Guenther	Temporal issues in life cycle assessment – A systematic review	2011	Temporal issues based on ISO 14040 are systematized and divided them into six types: time horizon, discounting, temporal resolution of the inventory, time-dependent characterization, dynamic weighting, and time-dependent normalization. Building on that, we identified suitable search terms and developed an analysis grid for the content analysis. We included only methodological papers and case studies with original findings on solutions for temporal issues. Bibliographic data, impact types, industrial fields, and methodological contributions were analyzed.	There are six direct temporal issues: time horizons, discounting, dynamic inventory, dynamic characterization, dynamic normalization, and dynamic weighting. Not considering them in LCA is a simplification that in some cases can have decisive influence on the outcome of LCA, potentially leading to wrong decisions. There is consensus in literature that the application of a dynamic inventory or a dynamic characterization improves the accuracy of LCA. A big concern with decisive influence on the LCA outcome is the setting of time horizons. There are three TH. Time-dependent weighting and normalization factors are rarely mentioned in literature. That may mean that there is no need for them because weighting is conducted in the viewpoint of the current stakeholders of the LCA and time-dependent normalization might be misleading.
9	M.Ammar Alzarrad, Gray P. Moynihan	4D BIM Simulation Guideline for Construction Visualization and Analysis of Renovation Projects	2021	4D BIM Simulation Guideline for Construction Visualization and Analysis of Renovation Projects" journal paper involved a comprehensive literature review, a case study, 4D BIM model creation, simulation and analysis, guidelines development, and validation. The proposed guideline has the potential to improve the construction visualization and analysis of renovation projects, leading to more	This paper tells about the Four-dimensional Building Information Modelling (4D BIM) is a powerful tool that combines 3D models with time or scheduling data, enabling construction professionals to visualize and analyse construction projects. This technology is particularly useful for renovation projects, as it allows stakeholders to understand how the construction will progress over time and anticipate potential problems. 4D BIM simulation is an invaluable tool for construction visualization and

				efficient and effective project management.	analysis of renovation projects. By creating a detailed 3D model and adding time or scheduling data, construction professionals can visualize the construction process, anticipate potential problems, and resolve conflicts before they occur.
10	RegitzeKjxrZimmermann, Simone Bruhn	BIM Based life cycle assessment of buildings an investigation of industry	2021	The methodology adopted in the "BIM Based Life Cycle Assessment of Buildings: An Investigation of Industry Practice and Needs" paper involved a literature review, survey design, survey administration, data analysis, gap analysis, and recommendations. The study provides valuable insights into the current industry practice and needs related to BIM-based LCA of buildings, which can guide future research and practice in this area	A BIM-based LCA involves using the BIM model to collect data on the building's embodied energy, carbon emissions, and other environmental impacts over its entire life cycle, from construction to demolition. The results of the LCA can then be used to inform design decisions and identify opportunities for improving the environmental performance of the building. Despite the potential benefits of BIMbased LCA, there are several challenges to its widespread adoption in the AEC industry. One of the main challenges is the lack of standardized methods for conducting BIM-based LCAs, which can make it difficult to compare results across different projects or regions. Additionally, many industry professionals lack the knowledge and skills needed to conduct BIMbased LCAs, and there is a need for more training and education in this area.
11	M.Dupuis, A.April	Method to enable LCA analysis through each level of development of a BIM model	2017	The methodology adopted in "A Method to Enable LCA Analysis through Each Level of Development of a BIM Model" paper involved the identification of LCA requirements, development of a BIM-LCA framework, BIM model development, integration of LCA analysis, data collection and analysis, comparison of LCA results, and evaluation of the BIMLCA framework. The study provides a useful approach to enable LCA	Life Cycle Assessment (LCA) is a methodology used to assess the environmental impacts of a building throughout its entire life cycle, from construction to demolition. Building Information Modelling (BIM) is a digital representation of a building that allows for information to be shared and analysed throughout the entire building process. Integrating LCA analysis into BIM models can provide valuable insights into the environmental performance of a building and enable better decision-making. Overall, integrating LCA

				analysis at each level of development of a BIM model, which can guide sustainable design decisions and improve the environmental performance of buildings.	analysis into BIM models can help improve the sustainability of buildings by providing valuable information that can be used to make more informed decisions throughout the building process.
12	Cristiane Bueno, Marcio Minto Fabricio	Comparitive analysis between a complete LCA study and results from a BIM-LCA plug-in	2018	This paper is based on the operational research method, i.e. a scientific approach to assist in the decision making process that aims to determine the best methods to design, plan and operate systems. In operational research, problems are broken down into basic components and then solved in predefined steps by using quantitative modelling and simulation as its methodological core. The use of modelling enables to better understand the studied system, identify problems, formulate strategies and opportunities, and provide support and systematization to the decision-making process. A model can be defined as a representation of reality and is built to assist in the treatment of any situation approached systematically. This paper employed the descriptive axiomatic research method and analyses quantitative models, particularly to understand the modelling process or explain its characteristics based on models that describe the behaviour of the system.	The results from the present evaluation and discussion of the comparison of practical tools application are considerably important to understand the current potentials and the remaining limitations of the BIM-based LCA tools under development, and thereby provide scientific and empirical basis to further develop the implementation of environmental based decision-making since the early design process. As pointed out in the literature review, one of the major problems identified by the studied authors was the difficulty of developing an LCA tool that fits into the initial design stages, when accurate data on the constructive systems is not available and the design solutions are not yet sufficiently detailed and consolidated. The software tool evaluated in the present research work showed it could fill this gap from the operational point of view, being sufficiently flexible and simplified to be applied in the initial design stages. Although the plug-in provides information on the applied environmental database, the number of constructive alternatives available to be correlated with the construction systems used by the Revit model is quite limited, leading the user to make assumptions on the most similar type of building component, what can lead to deviations in the final result.
13	Victoria Herrero-Garcia	Whole-Building Life Cycle Assessment: Comparison of Available Tools	2020	At first, the data is collected for each life cycle stage, including the raw materials, energy consumption, waste	It is observed that Athena IE provides reports, graphs, and tables for an individual project or for design comparisons and can be generated at any time

				generation, and emissions associated with the production, use, and disposal of the building.Several WBLCA tools such as Athena Impact Estimator, SimaPro, One click LCA and Tally are available, and the appropriate tool should be selected based on the scope of the study and the data collected.A model is created using the selected tool, which includes inputting the data collected and defining the system boundaries and assumptions.he environmental impacts associated with the building's life cycle is evaluated using the selected impact assessment method. The results obtained from the different tools should be compared, and any differences should be analysed to identify the underlying reasons.	during the analysis. Graph results only show one impact category at a time. Tables display results for all impact categories. Tally report generates a PDF document with graphs, LCA values, and EPD links, as well as a Microsoft Excel spreadsheet so users can develop their own graphic representations and operate on LCA data. No graphical representation is available prior to generating the report. One Click LCA has a variety of graphical representations generated automatically with every new entry to a project or when comparing design options so the users do not have to create their own visualizations. LCA data can be visualized at any time during the analysis. If desired, result reports could be exported into a Microsoft Excel file format and PDF format.

3. Results and Discussion:

The use of BIM as a tool in this study has simplified the process of selecting sustainable materials for Office buildings, the material take-off process, and the simulation necessary to assess how different building materials behave in terms of energy consumption. The BIM 3D model must include the physical and thermal characteristics of each material that will be used in the project. The modelling was constructed based on Degree of Development since the components are graphically represented as a specific object with information on specifics, manufacture, assembly, and installation.

OneClick LCA helps architects, interior designers, and builders make informed decisions about the materials and designs that can result in reduced carbon emissions in residential projects. As a result, it may help with the transition to a constructed environment that is more environmentally friendly and low-carbon. There are three variables in One Click LCA: Building materials, construction site operations, and building floor area are the first three. These qualities are necessary for the outcome of carbon emissions.

We conduct four trails. We continue to increase the amount of fly ash in ready-mix concrete and the amount of recycled material in reinforcement as we alter the paths. We use reused bricks and cement-free mortar.

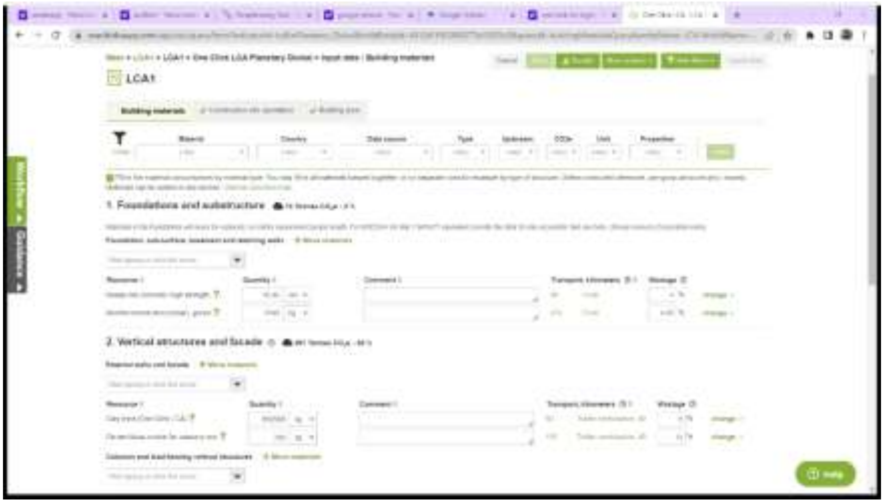

Fig. Submitting material quantities in One Click LCA

In the first trail, we utilize ready-mixed concrete with a 10% fly ash component in the cement, reinforcement steel with 0% recycled content, cementitious mortar for masonry work, clay bricks, and wooden framed balcony doors with an aluminum covering. It emits 1215 kg of CO2 per square meter. The entire structure emits 437 tonnes of CO2 in total. This indicates that it is inside the red range of the criterion for embodied carbon (> 510 kg CO2/m2).

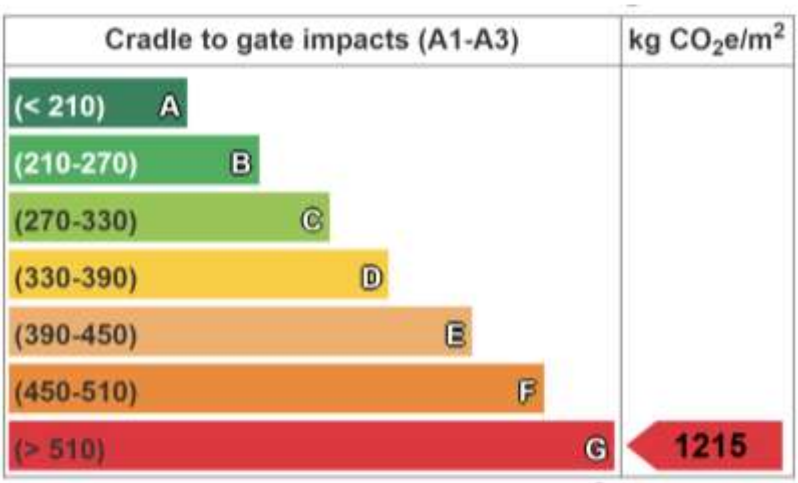

Fig. Embodied carbon benchmark of Trail-1

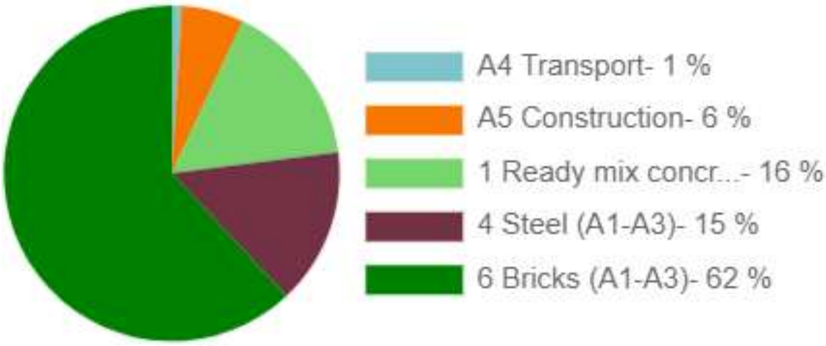

Fig. Embodied carbon emissions in life-cycle stages of Trail-1

In the second trail, we utilize cement-free mortar for masonry work, reinforcement steel with 15% recycled content, clay bricks, and wooden-framed balcony doors with aluminium coating. It produces 1159 kg/m2 of CO2. Total CO2 emissions from the entire structure are 417 tonnes. That indicates that it is still in the unacceptable red zone of the embodied carbon standard (> 510 kg CO2/m2).

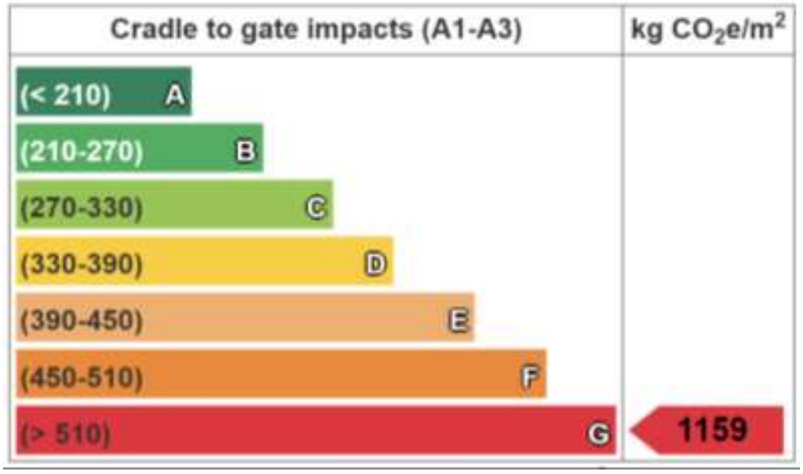

Fig. Embodied carbon benchmark of Trail-2

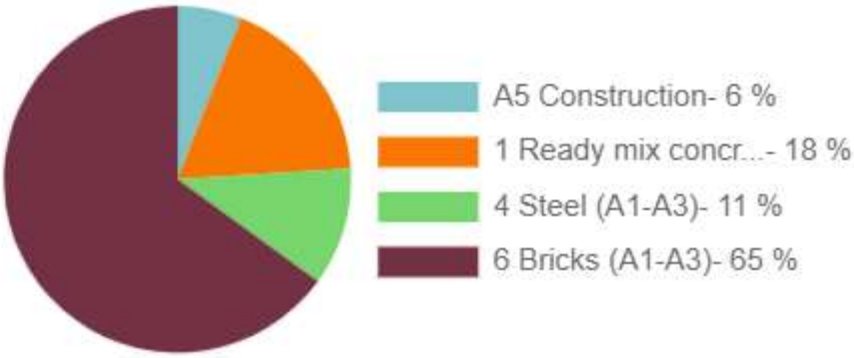

Fig. Embodied carbon emissions in life-cycle stages of Trail-2

In the third trail, we utilize ready-mix concrete that contains 30% fly ash in the cement, 60% recycled reinforcement steel, cement-free masonry mortar, reused bricks, and wooden framed balcony doors with aluminum covering. There is a 320 kg CO2/m2 emission. 115 tonnes of CO2 are emitted from the entire building. This indicates that it exceeds the permitted green range of the embodied carbon standard (270–330 kg CO2/m2).

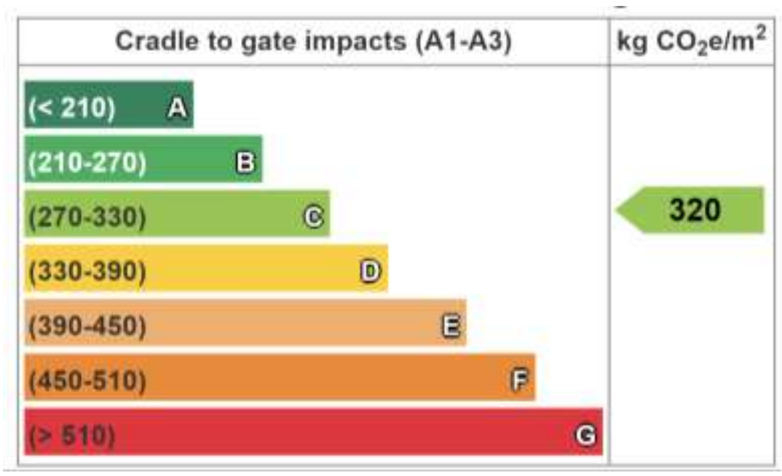

Fig. Embodied carbon benchmark of Trail-3

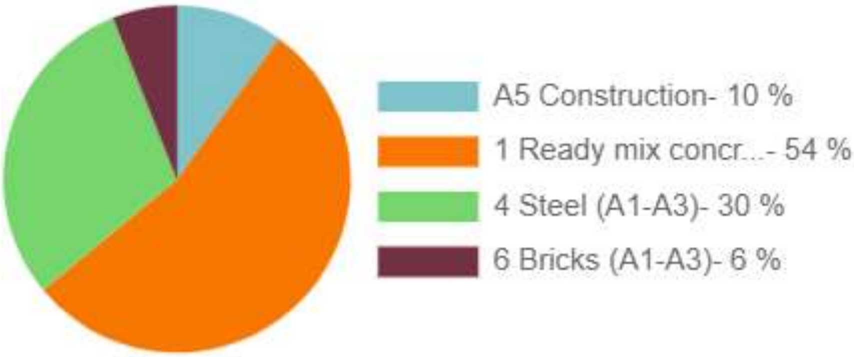

Fig. Embodied carbon emissions in life-cycle stages of Trail-3

For the fourth trail, we utilize recovered bricks, ready-mixed concrete with 30% fly ash in the cement, 100% recycled reinforcement steel, cement-free mortar for masonry work, and wooden framed balcony doors with aluminum covering. It produces 273 kg/m2 of CO2. 98 tonnes of CO2 are overall discharged from the building. This indicates that it remains within the green range of the benchmark for embodied carbon (270–330 kg CO2/m2), which is significantly more acceptable.

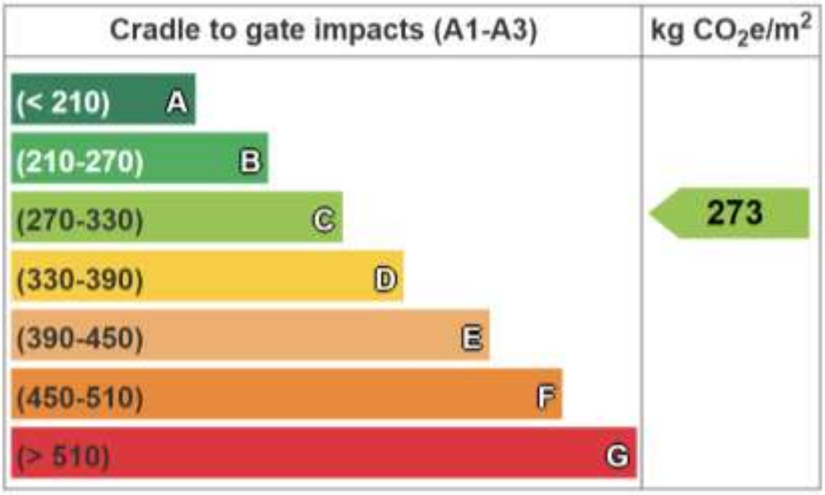

Fig.19 Embodied carbon benchmark of Trail-4

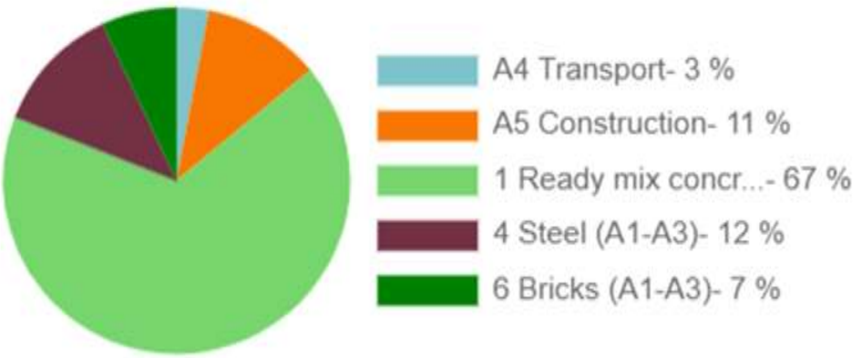

Fig. 20 Embodied carbon emissionsin life-cycle stages of Trail-4

Finally, of the four trails completed, the materials used in the fourth case are the only ones that can be termed sustainable because they produce less than one-fourth as much carbon dioxide as the trail's predecessor. When comparing these four trails, RMC concrete is responsible for 67% of the overall carbon emissions. This means that using environmentally friendly materials and sustainable resources can aid in the construction of environmentally friendly constructions and mitigate global warming.

Results indicating the reduction in CO_2emission with use of sustainable materials is shown in the **figure.**

Fig. Comparison of four alternatives tested via One click LCA

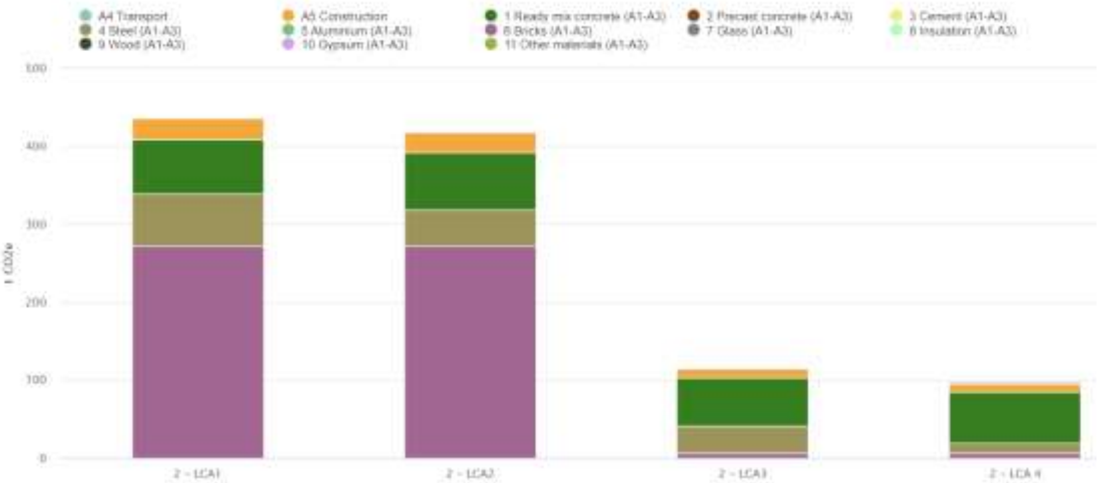

Fig. Comparison of carbon emissions through life cycle stages

4. Conclusion

Selecting sustainable materials for Office building construction using BIM and the Life Cycle Matrix tool is a crucial method for reducing the environmental impact of building development. With the use of BIM, which enables the production of virtual models of buildings, building designers, engineers, and architects may optimize building designs and assess the environmental impact of building materials. The Life Cycle Matrix tool enables the discovery of sustainable material substitutions with the least harmful environmental effects by providing a complete analysis of the environmental impact of building materials throughout their full life cycle.

Sustainable material options, like bamboo, recycled steel, and cellulose insulation, may be found and included into the building design using the technique described in this study. It is also found that recycled bricks reduce carbon emissions when compared to the ordinary clay bricks. These eco-friendly materials have less of an impact on the environment while yet being durable and structurally sound. The use of sustainable materials in Office building construction can contribute to a more sustainable future, where natural resources are utilised more efficiently, and the environment is safeguarded.

The findings of this study indicate that carbon emissions are mostly produced by building components such floors, beams, columns, and slabs, and that most of these emissions occur when a structure is being rebuilt. The study's findings emphasize the need of choosing sustainable building materials for office building development using a thorough and integrated strategy. It is possible to make more sustainable decisions that are good for the environment and the economy by looking at the full life cycle of building materials and using technologies like BIM and LCMT.

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