Review Article

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Life Cycle Assessment of an Institutional Building using Open LCA Software

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Abstract
There is a growing recognition in the construction industry of the need to reduce the environmental impacts of buildings and construction projects. This has led to a focus on quantifying and minimizing the energy, carbon, and material footprints of buildings and construction projects, as well as implementing sustainable design strategies. The combination of tools like Building Information Modeling (BIM) and Life Cycle Assessment (LCA) is becoming more common as a way to better understand the environmental impacts and identify opportunities for improvement. By taking a proactive approach to sustainability, the construction industry can play a key role in reducing the overall environmental impact of the built environment. This study focuses on a case study of analyzing the environmental impacts of different components of a building, such as columns, beams, masonry, and slabs, in an institutional building, and determining the impacts on the environment. Masonry with fired clay bricks was found to be the component with the maximum environmental impacts, and different alternative materials for replacement, such as fly ash bricks, were assessed in Open-LCA software using the Eco invent database. The environmental impacts of fired clay bricks and fly ash bricks were compared, and the results of the reduction in environmental impacts are presented.

Keywords: Life Cycle Assessment (LCA), Building Information Modeling (BIM), Open LCA, Environmental Impacts, Open LCA.

Introduction

The built environment accounts for one-third of all carbon dioxide emissions and uses about 40% of the world's total energy output. The rise in carbon emissions is one of the primary causes of global warming and climate change. Now all the nations are coming forward for achieving Net-Zero carbon emissions in the Paris Agreement. India has reaffirmed its Nationally Determined Contribution to achieve the long-term goal of reaching net zero by 2070. By contributing more than 5% to the Gross Domestic Product (GDP) of India, the building industry has indeed made a substantial contribution. In India, the building industry is the sole sector responsible for 24% of all sectors' CO2 emissions. The reduction of targeted GHG emissions in India is the main objective of the Climate Change Bill-2012 (India). Additionally, it promises to offer carbon trading and budgeting systems.

Carbon emissions refer to the amount of carbon dioxide and other carbon compounds released into the atmosphere. Buildings are a significant contributor to carbon emissions, as they often require a lot of energy for heating, cooling, lighting, and other functions. There are many ways to reduce the carbon emissions associated with buildings, such as improving energy efficiency, using renewable energy sources, and incorporating sustainable design practices. In many developed countries, such as the US, Australia, and Singapore, there is growing recognition of using sustainable construction strategies to reduce environmental impacts [1]. The usage of sustainable building materials is one of the important factors to reduce GHG emissions. Since the earliest civilizations, traditional brick has been widely adopted for use in construction. Due to its affordability, conventional brick is in high demand in today's rapidly growing construction industry. However, conventional bricks have an embodied energy of roughly 2.0 kWh. Regarding the elements that make up pollution, a conventional brick emits 0.41 kg of carbon dioxide per brick (Reddy and Jagadish n.d.). To improve the environmental performance of the bricks, it is mandatory to assess the entire life cycle of the material associated with the environmental impacts.

Using conventional bricks and bricks infused with biosolids, conducted LCA tests to analyze the environmental effects of each type of brick [2]. To reduce the limited brick soil, the amount of biosolids by dry weight was altered. The comparative analysis revealed that bricks infused with biosolids exhibited a reduced environmental impact. Furthermore, these biosolids-infused bricks exhibited lower embodied energy compared to conventional bricks that did not contain any biosolids. (Parrish and Chester 2014) cited that Life cycle assessment gives important details on the effects on the environment and different methods to decrease them. The Life Cycle Assessment (LCA) of a building reveals several environmental impacts. The LCA on a project can be performed even before construction starts to evaluate the environmental consequences, giving the contractor the chance to decrease the effects by selecting alternative construction materials [3]. The advantage of LCA is that it analyses the contributions made at each stage of the life cycle of a product, from the acquisition of raw materials to disposal at the end of its useful life. Combining this information not only provides a summary of the product's overall environmental impact but can also provide a road map for prioritizing efforts to mitigate those effects. Life cycle assessment practitioners frequently employ the pre-defined impact assessment methods provided by the LCA software package [4].

(Means and Guggemos 2015) utilized focus group comments to compare the existing LCA tools and approaches with a prepared framework. Gaps when developing an LCA-based environmental decision-making tool were discovered following a comparison of LCA-based environmental decision-making for commercial buildings. The databases used in the Life cycle assessment calculations are very important as they play a very important role in the analysis. (Azari and Palomera-Arias n.d.) concluded that the Athena impact estimator, a tool for LCA, had relatively little data on building materials. (Martínez-Rocamora et al. 2016) collected information from 10 different databases and discovered that relatively few of them provide information on building materials. The study also showed that the GaBi and Ecoinvent databases are more reliable. (Emami et al. 2019) revealed from his studies that accurate information is very much important in the construction industry for decision-making using Life cycle assessment tools.

This study focuses on the Life Cycle Assessment (LCA) of an institutional building using Building Information Modeling (BIM) and Open LCA software which is widely used in many parts of the world. The eco-invent database is used for the product information in this study to perform LCA. The combination of the Open-LCA software and the eco-invent database is expected to yield superior outcomes compared to other software-database combinations. The selection of the Open-LCA software was driven by its cost-free nature and its potential to deliver improved environmental impact results in the construction sector. The combination of Open LCA software and BIM will help builders and owners to assess the environmental activities of the building. Before commencing construction activities, conducting an LCA study enables contractors to assess the environmental consequences arising from building materials. By opting for alternative construction materials with reduced environmental impacts, it becomes possible to mitigate the overall effects.

Materials used in Construction

Cement, bricks, sand (fine aggregate), gravel (coarse aggregate), steel, and water are the main building materials. These materials are all limited, and over usage of them will have a negative influence on the ecosystem. Fired clay bricks have greater negative environmental impacts because of scarce clay used in its production and firing process which emits harmful gases into the environment.

Fired Clay Bricks

According to estimates, 250 billion bricks are produced in India annually, making it the second-largest brick producer in the world. With the 6.6% annual growth rate, there will be increased demand for building materials, particularly bricks. Burnt red clay bricks have a risk of causing land degradation because they require fertile soil, and good-textured, silty, clayey soil in order to produce good-quality bricks. The land becomes unproductive when the fertile topsoil is removed. Research conducted by stated that the removal of topsoil for the preparation of bricks resulted in the reduction of manganese and zinc was approximately 35% and 63%. In addition to this, the loss of 28 kg of nitrogen, 3 kg of phosphorous and 34 kg of potash per hectare of land [5]. In addition to the degradation of land, burning clay bricks releases toxic gases into the air which are released while production of bricks. It is estimated that the Indian brick Industry liberates 80.7 kg of CO2 per thousand bricks due to the firing of coal as a fuel for brick manufacturing [6].

Fly Ash Bricks

Due to their eco-friendliness and potential qualities, fly ash bricks, a sustainable substitute for conventional clay bricks, have attracted a lot of interest these days. These bricks, which are produced from fly ash, a by- product of coal combustion, reduce waste while also providing other benefits. According to research, fly ash bricks have high strength and durability, which makes them appropriate for use in various construction applications. According to a recent report by the Central Electricity Authority (CEA), coal-based power plants contribute roughly 57% of the total amount of power generated in India (Central Electricity Authority CEA ANNUAL REPORT 2021-22 CENTRAL ELECTRICITY AUTHORITY MINISTRY OF POWER GOVERNMENT OF INDIA n.d.). 167 thermal power plants using coal or lignite are currently operational in India, consuming over 625 million tonnes of coal, or almost three-fourths of the nation's total coal consumption. Because of this, a significant amount of fly ash is being produced, amounting to over 196 million tonnes in 2017–2018.

Case Study

Life Cycle Assessment (LCA) is one of the techniques used for assessing potential environmental impacts (Vélez-Henao 2020). LCA is very important as a sustainable tool as early decisions can be taken using this to detect environmental burdens and assess the environmental impact of a product or process throughout its life cycle. An educational building is chosen for analyzing the environmental impacts of its elements. Fig 2 represents the Materials and Metallurgical Engineering building in the National Institute of Technology, Warangal, Telangana, India is a G+6 floor building with Labs, classrooms and staff cabins. A 3D model of the building was developed in Revit software. For the calculation of the environmental impacts of the building and its materials, we need the quantities of material. So, the quantities of materials were extracted from the Material take-off in the Revit software. Material quantities of important components of the building such as columns, beams, floor, staircase and masonry were calculated. Material quantities for column is 701.84 m3, Beam 1154.93 m3, Staircase 104.88 m3, Floor slabs 4707.28 m3, Masonry quantity is 5170 m3.

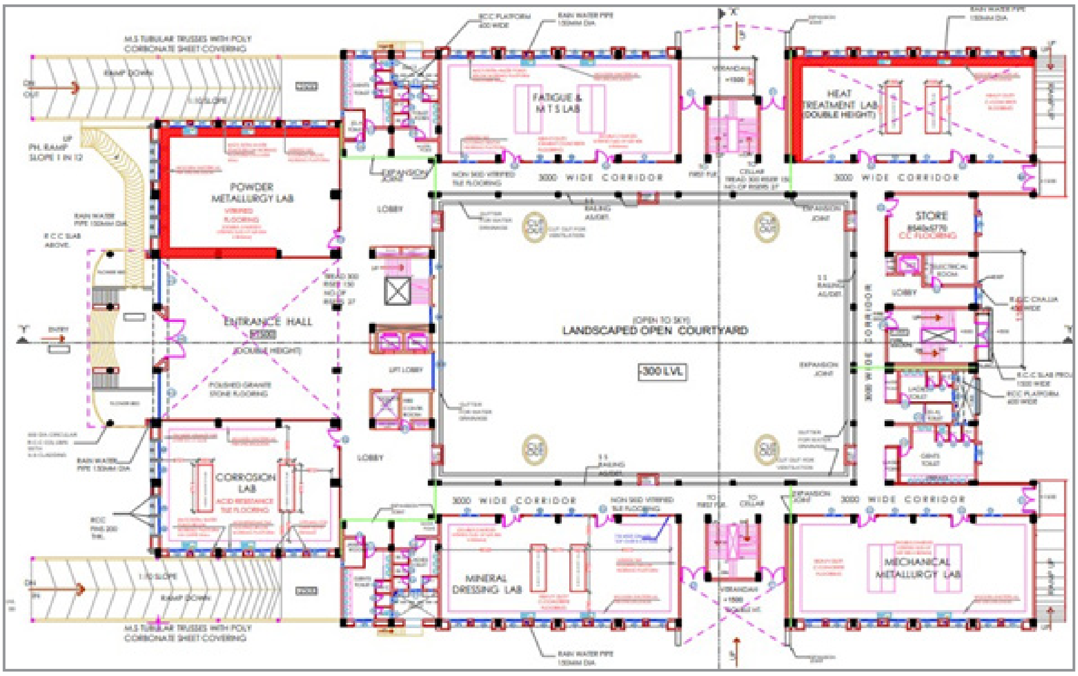


Figure 1: Ground floor plan of case study building

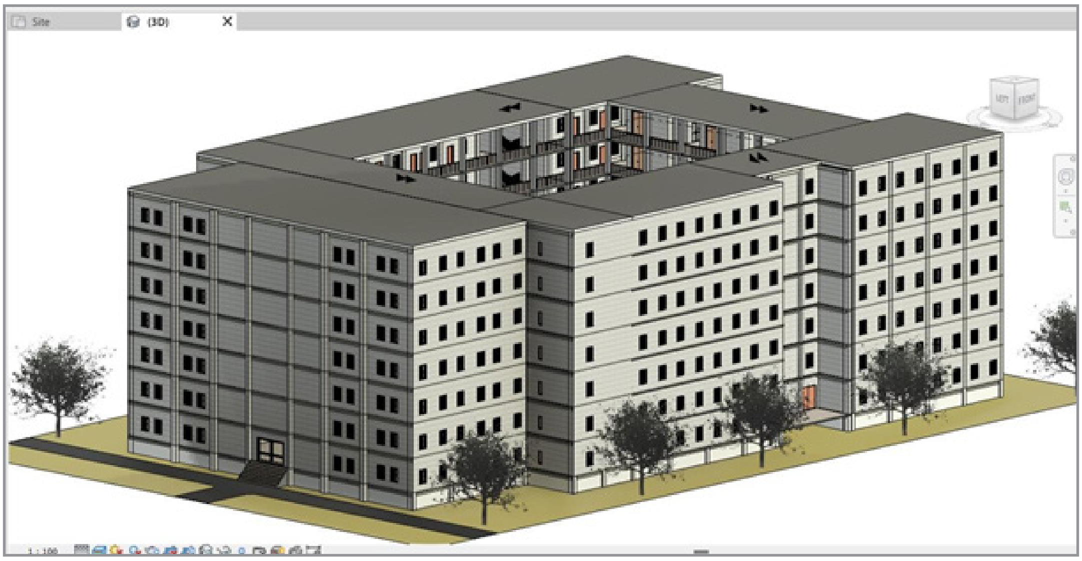


Figure 2: Revit 3D model of case study building

Methodology

This study focuses on the impacts of different components of the building such as columns, beams, masonry, staircase and slab by quantifying their material quantity from a 3D Revit model. The component with high environmental impacts is replaced with better alternatives.

LCA methodology has four stages

- i. **Goal and scope definition:** This stage involves defining the goals and objectives of the life cycle analysis, as well as determining the scope of the study. This includes identifying which product or service will be analysed, as well as the time frame and geographic region that will be covered. The research is intended to specify the environmental impacts associated with Fired clay brick, Fly ash brick and case study brick for decision-making of selection of the brick with lower impacts. The scope of this study is limited to the calculation of impacts of the materials from cradle-to-gate i.e., from raw material extraction, transportation to plant and production.
- ii. **Inventory analysis:** This stage involves collecting data on the inputs and outputs associated with each stage of the product's life cycle. This includes information on raw materials, energy and water use, emissions, and waste generation. Eco-invent v3.6 database has been used in this study.
- iii. **Impact assessment:** This stage involves evaluating the environmental impacts of the product's life cycle. This can include assessing the impact on air and water quality, soil and water resources, and greenhouse gas emissions. ReCiPe midpoint (I), CML IA Baseline, and Ecological footprint

methods are considered in this study.

- iv. **Data Interpretation:** This stage involves analysing the results of the impact assessment and identifying opportunities for improving the product's sustainability. This can include making recommendations for reducing energy and water use, reducing emissions, and improving waste management practices.

The functional unit in this study is the manufacturing of 1m3 of product. The building is divided into major components such as columns, beams, staircases, slabs and masonry. Each component of the building has been defined as a process and the materials required for constructing it as input and parameters. As assumed, only human labour is taken into consideration in the construction process and machinery is excluded.

Results and Comparison

This research paper aims to identify the primary factors that contribute to environmental impacts, such as ecosystem acidification and eutrophication, fossil fuels, human toxicity, climate change, human health carcinogens, ecotoxicity, human health respiratory effects, ozone depletion, ecosystem quality, marine toxicity, mineral extraction, and CO2 emissions. Each component was calculated for its impacts in various impact categories. The environmental impacts resulting from the construction materials are also assessed and compared. In this study, Fly ash bricks are manufactured in a plant called KSP Fly ash brick manufacturers in he village called Bibipet near the outskirts of Hyderabad. Raw material such as Fly ash is transported from Kakatiya Thermal Power Plant (KTPP) near Chelpur, Warangal. The distance between them is 180 Km. Stone dust required for the fly ash brick is transported from stone quarries locally within a 25 km range.

Impacts by the Components

Graphs were extracted from CML 2016 IA Baseline, ReCiPe Midpoint (I) V1.13 and Ecological footprint LCIA methods. These graphs of different methods were separately exported to Excel sheets. Then, similar environmental impacts for different building components were analyzed for environmental effects. Through a comparison of building components with other elements, the environmental impacts generated have been analyzed. The results indicate that masonry work emerges as the primary contributor to the mentioned environmental impacts. Fig 3-11 gives the environmental impacts of different categories.

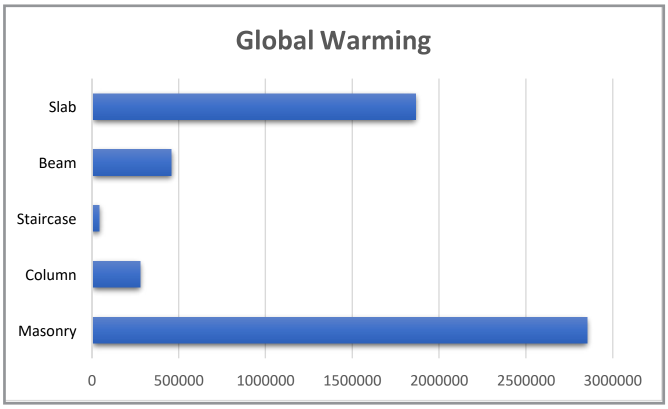


Figure 3: Graph comparison of components for Global warming (units as points)

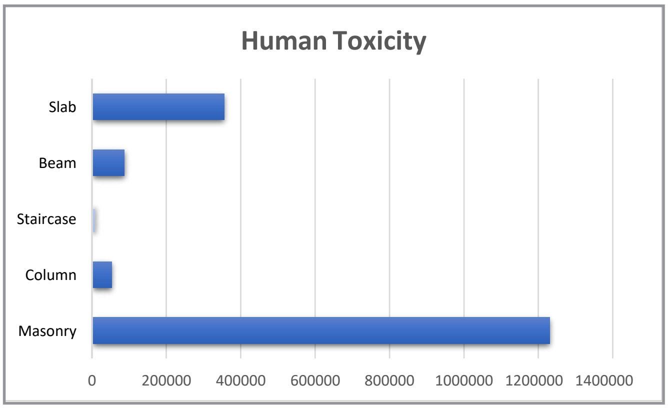


Figure 4: Graph comparison of components for Human toxicity (kg 1,4-DCB)

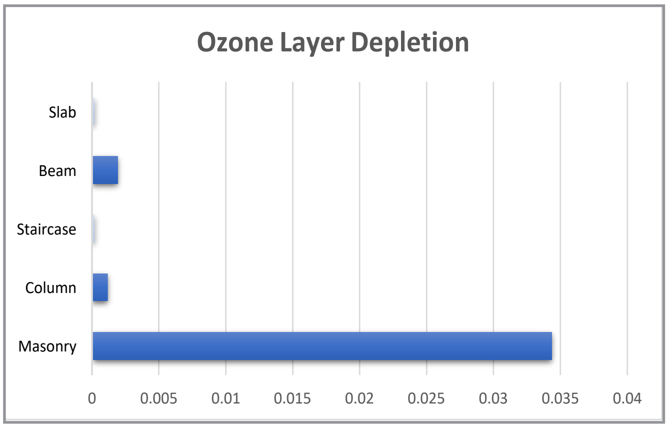


Figure 5: Graph comparison of components for Ozone Layer Depletion (units as points)

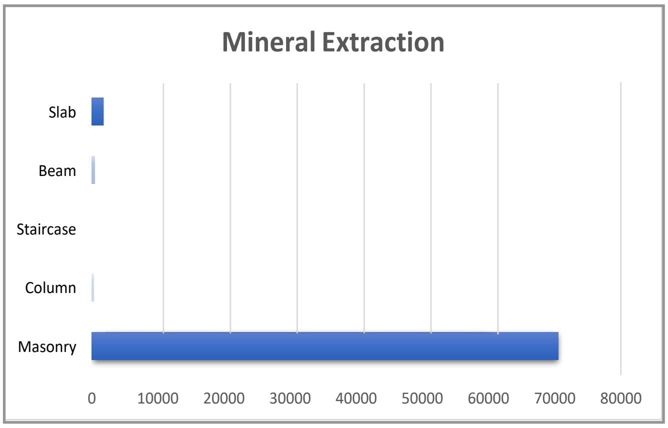
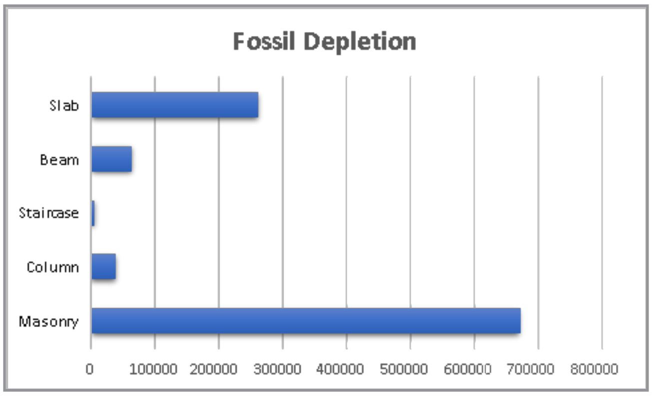


Figure 6: Graph comparison of components for Mineral Extraction (units as points)



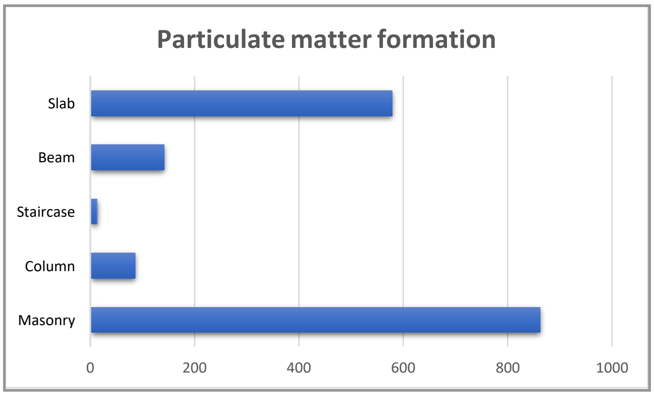
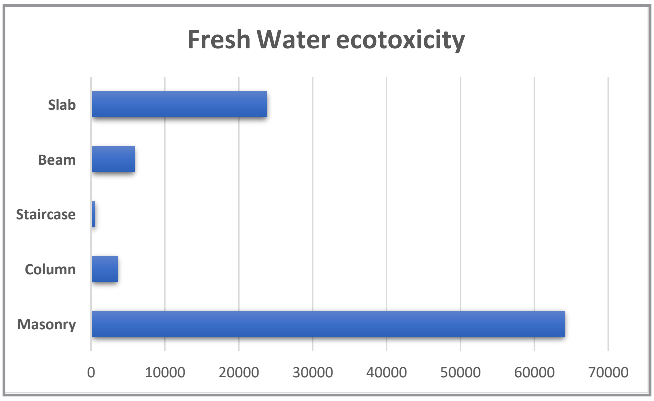


Figure 7: Graph comparison of components for Fossil Depletion impact (kg oil-Eq)

Figure 8: Graph comparison of components for Particulate matter formation (kg PM2.5 eq)



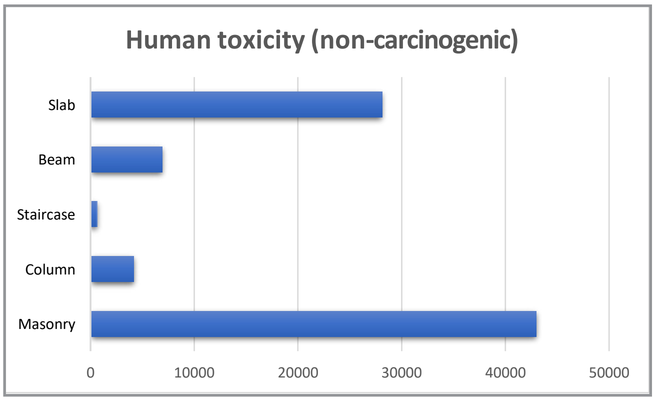


Figure 9: Graph comparison of components for Freshwater ecotoxicity (units as points)

Figure 10: Graph comparison of components for Human toxicity (non-carcinogenic) (kg 1,4- DCB)

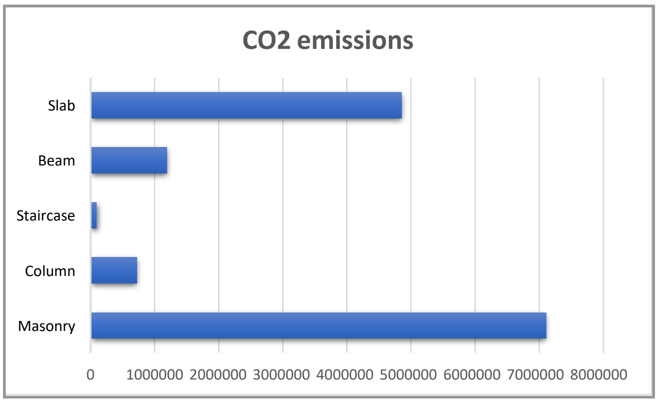


Figure 11: Graph comparison of components for CO2 footprint impact (m2a)

From the analysis, it is evident that Masonry work (brick) is the highest major contributor to environmental impacts. This is due to the fact that fired clay bricks used in masonry are made from natural resources like clay which is obtained from the top layer of the fertile soil. This layer is removed to make clay moulds. Moreover, the process of fired clay brick manufacturing involves burning the brick moulds which emit harmful gases into the environment. Thus, manufacturing of the fired clay brick is the major contributor to the environmental impacts. The next major negative contributor to fired clay bricks is slab. As the case study building is an educational building with six floors which is supposed to bear heavy dead loads and live loads, a large amount of concrete is used in the slab.

As concrete manufacturing involves clinkerisation, heating of raw materials and transportation of the materials to the site, all these activities add up to give environmental impacts. Concrete manufacturing is one of the highest emitters of harmful greenhouse gases in the construction industry.

Impacts by Alternate Materials

As fired clay brick masonry is having a major contribution to the environmental impacts, fired clay brick is replaced with alternative brick materials such as Fly ash brick. 2 cases of Fly ash bricks are used in this study. Case study 1 refers to the Fly ash brick manufactured with the guidelines given by the IS code and case study 2 refers to the fly ash brick manufactured in the local fly ash brick manufacturing site. A company named KSP fly ash brick manufacturers near Bibipet, Hyderabad was chosen to compare the environmental impacts of the alternative materials. A comparison of environmental impacts in different methods is shown in figures from Fig 12-16.

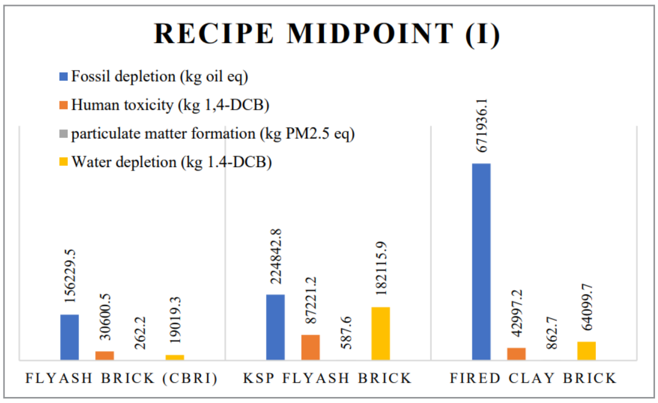


Figure 12: ReCiPe Midpoint (I) impact category for different bricks

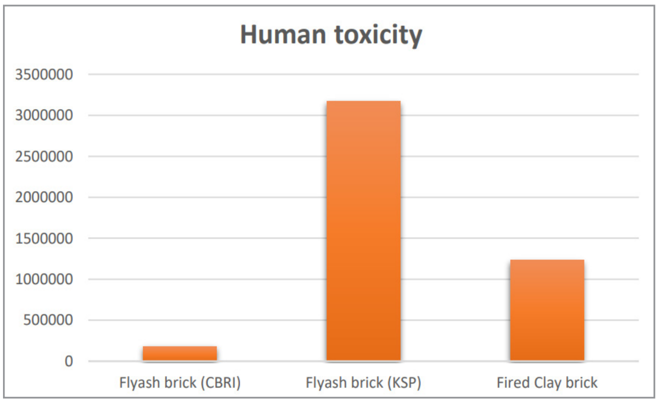


Figure 13: Comparison of Human toxicity for different bricks

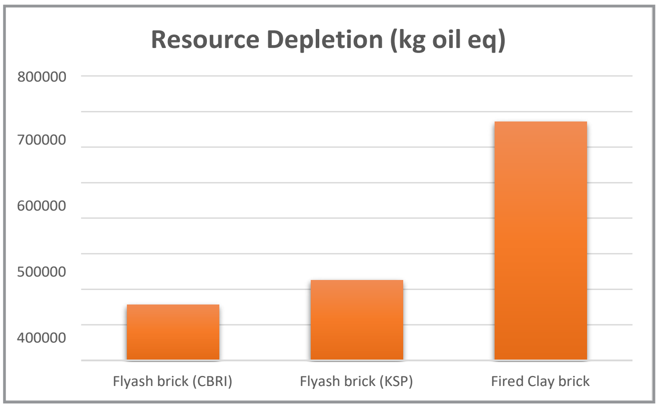


Figure 14: Comparison of Resource depletion for alternative bricks

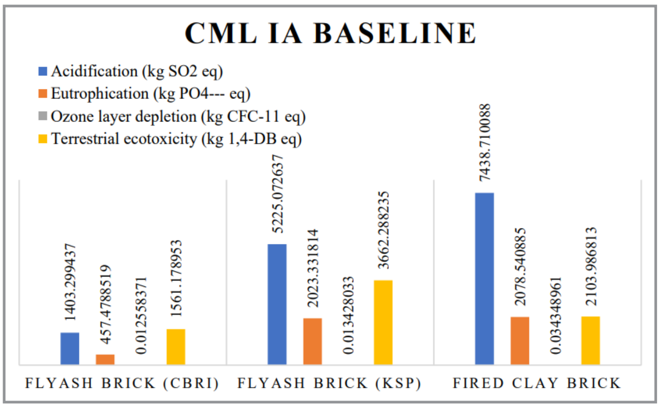


Figure 15: CML IA Baseline impact category for different bricks

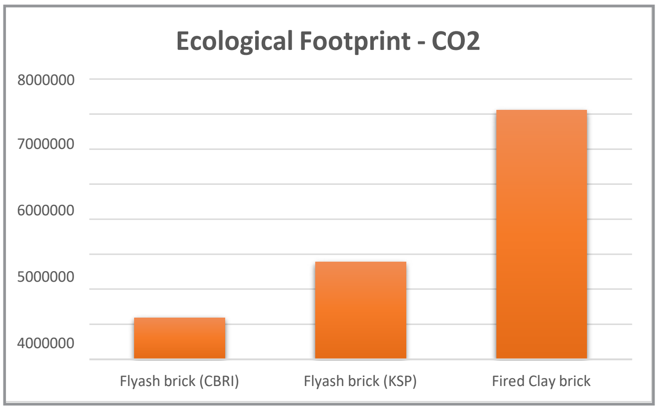


Figure 16: Ecological footprint (CO2) for alternative bricks

Summary and Conclusion

The present study has conducted an evaluation and comparison of the environmental impacts associated with fired clay bricks, fly ash bricks (CBRI), and Fly ash bricks (KSP) using ReCiPe Midpoint (I) method, CML IA Baseline method and Ecological footprint method. The production process and life cycle inventory of different bricks were identified. Next, impacts of different building components such as masonry, column, beam, slab and staircase were compared with LCIA impact categories and Masonry was found to be the building component (material) with the highest environmental impacts. Then, different bricks were evaluated and compared using the 3 LCIA methods mentioned above. Fired clay brick has the highest environmental impact among all 3 bricks.

The majority of environmental problems are caused by the materials used in buildings. Construction materials are produced using limited resources that are only found in limited amounts on Earth. A building's Life Cycle Assessment (LCA) reveals a broad range of environmental effects. The LCA can be carried out on a building even before construction activities begin to identify the environmental implications, allowing the contractor the opportunity to minimize the environmental impacts by choosing alternative building materials. Various effect categories, such as CO2 emissions, water depletion, ozone layer depletion, etc., can be used to calculate impacts. The usage of natural clay and the burning of raw moulds in kilns are the main reasons for the impacts of fired clay bricks. CML IA baseline, ReCiPe midpoint (I), and Ecological footprint method graphs showed that Fired clay bricks have the highest impact in each category. Fired clay brick and Fly ash brick in case study 2 (KSP) have similar environmental impacts in the CML IA Baseline method and Acidification has the major potential impact. Combined environmental impacts like Acidification and eutrophication potential, ozone layer depletion and Terrestrial ecotoxicity can be lowered by 3.4 times by using Fly ash brick (CBRI). Fired clay bricks cause the highest Resource depletion in the environment. The reason can be attributed to the usage of natural clay in production and excess waste generated by unburnt and overburnt bricks. This depletion can be reduced by 4.3

times by using fly ash bricks. As fly ash is a waste by-product from thermal power plants, there is very minimal damage to the environment. CO2 emissions are highest in fired clay brick compared to fly ash brick. This is due to the burning of brick mould in kilns with fuel. These emissions can be lowered by 5.9 times by using fly ash bricks. From the above study, there was an attempt to calculate the impact by locally manufactured fly ash bricks and it was compared with the impacts by fired clay bricks and standard fly ash bricks [7-36].

Scope for Future Study

The Life Cycle Analysis conducted on the building identified the components and materials that have the most significant environmental impacts. This study can serve as a basis for the development of alternative building materials, such as utilizing industrial waste or materials with low embodied energy.

Declaration of Competing Interest

The authors declare that they have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study's conception and design. Data collection, methodology, analysis, and writing original drafts were performed by Abhishek Kulkarni. This work was supervised by Dr. MVN Sivakumar.

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