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# Life Cycle Assessment of Cementitious and Clay Bricks

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**Abstract.** Construction is a demanding sector, requiring substantial energy and non-renewable resources. Also, it causes detrimental environmental impact. Amongst all the building materials, traditional fire-burnt clay bricks are used exclusively in many developing countries. Although, significant efforts are put into encouraging the use of alternative bricks (e.g., cementitious bricks, clay bricks enhanced with organic matters, etc.) which are perceived to be viable environmentally and economically but to bring about true recognition of the exact level of effects on natural sphere, environmental offsets are not always quantified but conveyed orally when it comes to using conventional bricks, being largely unaware of the harmful effects it brings during all the stages of manufacture, transportation and installation of the stated product. Past scientific sources covered life cycle assessment of traditional bricks with suitable substitutes along with their comparative analysis. Also, the challenges of obtaining accurate data to conduct the evaluation were focused upon. But most of the previous works did not conduct an expanded examination of clay and other types of bricks by considering many environmental categories. This paper aimed at investigating the life cycle analysis of two 1m*1m walls made with clay and cement bricks respectively using SIMAPRO software. Seven impact classes were considered to carry out the assessment such as climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, and photochemical oxidation. Results showed that utilizing cement bricks in the fabrication of structural members posed lower impact to the environment compared to the wall made with traditional bricks.

**Keywords.** Life cycle assessment, environmental impact, construction, traditional bricks, climate change, ozone depletion, human toxicity

## 1. Introduction

Construction is a very important industry for many generations and centuries. It is still considered antiquated, using traditional methods of using manpower. Additionally, the large consumption of resources and generation of waste and pollutants pose a threat to the status of the environmental equilibrium that must be maintained. With the advancement of technology and science, there are initiatives taken to reduce the carbon footprint in its processes and make it more economic and environmentally friendly.

Life Cycle Assessment (LCA) is a methodology adopted to assess the environmental impacts associated with a product or a service throughout its entire life

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cycle, from production until the end of life. LCA has many benefits that can help engineers and scientists to detect the flaws in a system to reduce its impact on the environment and help ensure sustainability [1]. Some of the benefits of LCA are the ability of quantifying the effects such as consumption of energy or resources, allowing the comparison of alternative solutions proposed, analyzing to recognize the scale of significant impacts throughout the life cycle, and providing a cost benefit study to produce an efficient and economic result/decision.

In recent years, many studies focused on the life cycle assessment (LCA) of bricks and their substitutes as a construction material. For instance, Kumbhar et al. (2014) recognized the environmental effects of fired burnt clay bricks in the Western Maharashtra of India. Stages of materials collection, transportation, and production of fired burnt clay bricks were taken into account. LCA was done using SIMAPRO to quantify energy use, greenhouse gases (GHGs) emissions, resource reduction and detrimental impact on biodiversity [2]. Zhang and Biswas (2021) assessed the technical, environmental, and economical performance of both interlocking and traditional bricks in a life cycle assessment approach. It was found that interlocking bricks demonstrated superior mechanical performance in terms of both compressive and tensile strength & had low environmental impacts. Conventional bricks could not be termed "eco-efficient" due to their high environmental loads [3]. Bories et al. (2016) developed porous fired clay bricks by using vegetative and chemical additives. LCA was performed on the substitutes and it was concluded that the incorporation of pores into the conventional bricks caused 15-20 % reductions in all types of impact categories [4]. Christoforou (2016) evaluated the energy requirement by performing LCA on adobe under three scenarios: on-site production with locally available soil and transported straw or sawdust, on-site production with transported soil and straw or sawdust, and in-factory production. Results revealed that reduced transportation and the utilization of locally available materials greatly influenced the environmental effects. Also, the use of sawdust instead of straw enhanced environmental performance [5]. Landi et al. (2022) carried out LCA for smart bricks monitoring systems. Two types of smart brick models were fabricated, and they were found to be more durable than the traditional ones with strain gauge sensors but in some impact categories, smart bricks caused more environmental effects compared to conventional bricks. Therefore, more sustainable components in the manufacture of smart bricks were encouraged to be discovered [6]. Nouri et al (2023) investigated the energy requirements and carbon dioxide emission for both rammed earth and fired clay bricks constructions and drew comparisons. It was discerned that rammed earth emitted significantly less $CO_2$ by 1245 kg/ton. Also, embedded energy was also reduced by 95% using the indigenous material [7]. Mohajerani et al. (2018) brought forth LCAs of bricks incorporating biosolids from two different treatment plants. LCAs conducted incorporating biosolids into bricks caused less environmental impacts. However, more water requirement was observed for both biosolid enhanced bricks. Also, for one biosolid type, transportation caused more ozone depletion and acidification compared to the other [8]. Huarachi et al. (2019) provided a thorough review of the LCA of different types of bricks. It was found that the analysis mainly covered traditional bricks, bricks with organic additives and bricks with inorganic constituents. For all the cases, climatic change, human toxicity and freshwater eco-toxicity were considered when performing the LCAs. The production process imparted the most environmental impact. Non-traditional bricks did not have stabilization process by firing which was a positive attribute [9]. Lozano-Miralles et al. (2018) did a study on the LCA of clay bricks incorporated with organic wastes. Both laboratory investigation and SIMAPRO ReCiPe midpoint method were used to assess energy requirement and gaseous emissions during the lifetime of the product. The organic matter addition to the conventional bricks caused about 15-20% less environmental impact in all the categories [10].

From the previous literatures, it is elucidated that in most cases, LCA of traditional bricks with alternative bricks fabricated with organic matters as ingredients was performed. Also, most studies only factored into climate impact, embedded energy and emissions when conducting the LCAs. This study aimed at conducting LCA of cementitious bricks and traditional fire-burnt clay bricks by considering their manufacture, transportation, and installation phases as boundary conditions. Also, this particular work emphasized on seven environmental impact categories (i.e., climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, and photochemical oxidation).

## 2. Materials and Methods

The SimaPro was used for conducting LCA. The study selected all the Ecoinvent 3 libraries for facilitating the incorporation of relevant resources under the construction, transportation, and installation of bricks by considering the materials used. Also, method was selected for the actual LCA of the said products using the chosen materials.

A total weight of 163.43 kg for clay bricks was considered. To manufacture the bricks, approximately 45% clay, 3% sand, 37% limestone and 15% water were used and their corresponding weights in kg were inserted. Similarly, for cement bricks weighing a total of 150 kg, 35% limestone, 29% clay (provided in place of alumina as this database was absent from Ecoinvent), 18% Portland cement, 15% water and 3% sand were used.

For the transportation of the said number of bricks, 10.13 ton-kilometers was proposed. Whereas 9.30 tkm was found after assumption and calculation for transporting 150 kg of cement bricks to site. For the wall 1m*1m wall fabrication with a total of 150 kg of cement bricks, 17.3 kg of mortar to bind the wall similarly, for clay bricks installation to construct the desired wall, adhesive mortar of 21.40 kg was used with the bricks themselves. All the processes related to the production, transportation and installation of both cement and clay bricks were properly labelled and saved under a single category for convenient LCA and future access. One Assumption was that no wastage at site during all the phases of the life cycle of the bricks.

## 3. Results and Discussion

By creating the LCA analysis assembly and incorporating the system boundaries, and also choosing the analysis method to midpoint, outcomes were obtained for the product (i.e., 1m*1m wall) by using both cementitious and clay bricks.

By referring to the characterization of cement brick wall, it is discerned that out of all the impacts, human toxicity was mostly impacted by cement bricks installation by around 83.4 %. Climate Change owned the lowest impact around 70.4%, with respect to the other impact in the installation process. As for clay bricks production, marine Eutrophication proved to have the lowest impact of around 0.186%, while the Freshwater eutrophication had the highest impact out of all the impact categories, around 10.8%. Photochemical oxidant formation was influenced in a similar fashion by cement bricks fabrication by more than 20%. Ozone depletion and human toxicity created the highest impact due to cement bricks manufacturing process. In all midpoint environmental impacts, cement bricks transportation created the least effects compared to production and installation. This ranged 0.296% to 2.94% (almost negligible) figure 1(a). Similarly, normalization chart represented the impacts as unit less numerical values. From the figure, it could be observed that freshwater eutrophication had the most impact out of all the 07 (seven) environmental impacts when LCA of cement bricks was conducted. Human toxicity came in second to be the most influential aspect. Climate change and terrestrial acidification both provided almost the same magnitude of impact. Ozone depletion caused the least environmental effect out of all the midpoint indicators considered figure 1(b).

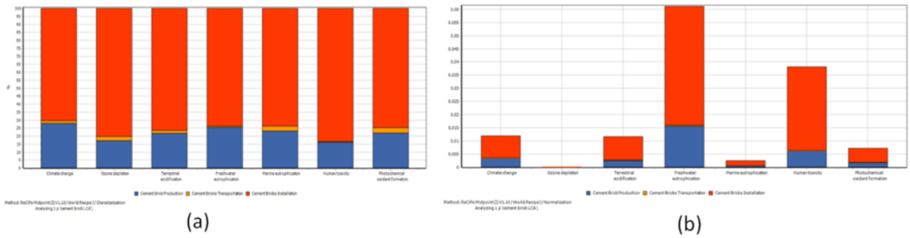



**Figure 1.** (a) Characterization and (b) Normalization for cementitious brick wall.

Under the characterization chart for clay bricks, it could be discerned that installation played the major role for most of the environmental impact categories, ranging from 90.3%-99.8%. Production and transportation posed little/no environmental significance. For production, freshwater eutrophication had the highest impact (i.e., around 12%). Whereas, climate change, ozone depletion and photochemical oxidation had between 5-10% environmental effects. Terrestrial acidification and human toxicity both constituted less than 5% environmental impact. Marine eutrophication had negligible effect under production. Under transportation, photochemical oxidant formation had a noticeable impact of about 3%. Climate change and ozone depletion had around 2% impact. Terrestrial acidification had about 2% effect. The remaining aspects had slight influence figure 2(a). Normalization diagram for clay bricks' LCA revealed that Marine eutrophication was the dominant factor for creating environmental degradation. Whereas freshwater eutrophication and Human toxicity took the place for being the second and the third most relevant parameters when LCA for clay bricks was considered. Also, ozone depletion caused the least impact out of all the 07 (seven) impactful aspects figure 2(b).

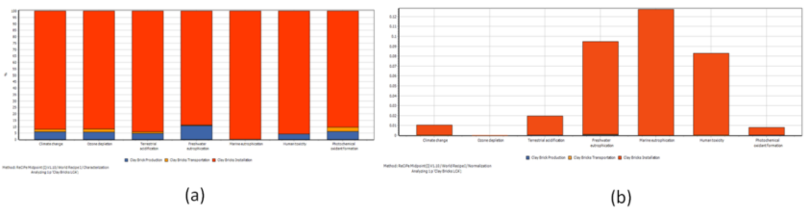
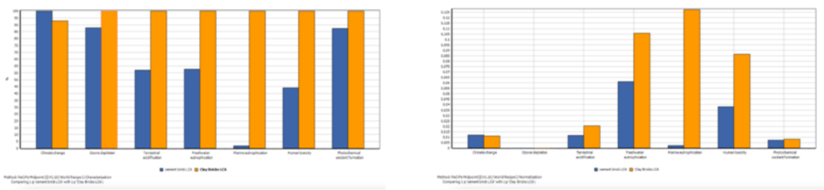



**Figure 2.** (a) Characterization and (b) Normalization for clay wall.

Comparative characterization between cement and clay bricks revealed that in almost all the impacts, clay bricks LCA was the most influential (i.e., causing 100% impacts) except for climate change. On the other hand, cement bricks LCA only superseded clay bricks LCA in climate change class. In all other classes, cement bricks were less impactful. For terrestrial acidification, freshwater eutrophication, human toxicity and marine eutrophication, the use of cement bricks in the construction of structural component showed promising outcome as these impacts were almost half compared to clay bricks figure 3(a). Normalization bar chart for comparative LCA shows that Marine eutrophication was governed mostly by clay bricks LCA and it was the least driven by cement bricks LCA. Out of all the impact categories, cement and clay bricks had almost the same hold for climate change and photochemical oxidation. Ozone depletion was the least impactful when utilizing the two material choices for the construction of wall with predefined dimensions figure 3(b).



(a) (b)

**Figure 3.** Comparative (a) characterization and (b) normalization for cement and clay bricks.

The limitations faced in the study started with the expired license of the software SimaPro, which resulted in dealing with a simulator that contained an old version of the database which led to inaccurate results; however, the ultimate efforts have been conducted to reduce the error as much as possible. In addition, the absence of cooperation from manufacturing factories and suppliers to provide data regarding the production stage of the bricks has created a challenge to the study. Also, attempt was made to find information of combustion related information in the production of clay bricks but due to the lack of proper information and subsequent input into the SimaPro software, production stage for LCA caused the least detrimental effects to the environment which is not practically correct in terms of climate change and ozone depletion. As the release of GHG due to the burning of fossil fuel in the fabrication of clay bricks causes major effects to the atmosphere. Further studies are required along with updated SimaPro databases to refine the existing LCAs and draw fruitful conclusions. Despite the shortcomings, wall fabricated with cementitious bricks seemed to be more environmentally friendly as opposed to traditional bricks. This finding aligned with the feasibility of using alternative bricks which was backed by previous studies [3,4,7,10].

## 4. Conclusion

From the results arising out of the LCA for both cement and clay bricks it could be deduced that installation caused the most impacts in all impact categories. Also, the materials (i.e., cement and clay bricks) were the major drivers to provide environmental loads to the installation process which in turn affected the final lifecycle assessment.

Adhesive mortar came out to be the second cause for the extent of environmental degradation. In both cases, production and transportation posed no impact. Comparative analysis between cement and clay bricks wall revealed that the use of cement bricks in wall construction was the most viable because it caused less environmental impact compared to the use of clay bricks. Due to the limitation of the project in acquiring country specific relevant data in compliance with the existing SimaPro database, accurate assessment could not be done. In the future, similar types of LCA using bricks of different compositions could be conducted and compared to find out the best possible alternative in terms of production, transportation, and installation.

## Competing Interests

All the authors involved in the preparation of the manuscript are well aware that the contents in the paper are original and have not been published or in the process of review and publication elsewhere. Also, there are no financial interests to report.

## References


[1] Juem F, Sinno S, Mortula M. Environmental sustainability assessment of wastewater treatment processes: case study. International Conference on Construction in the 21st Century. 2022。

[2] Kumbhar S, Kulkarni N, Rao AB. Environmental life cycle assessment of traditional bricks in western Maharashtra, India. Energy Procedia. 2014; 54(022): 260–269.

[3] Zhang X and Biswas WK. Development of eco-efficient bricks – A life cycle assessment approach. J. Build. Eng. 2021; 42: 102429.

[4] Bories C, Vedrenne E, Paulhe-Massol A, Vilarem G and Sablayrolles C. Development of porous fired clay bricks with bio-based additives: Study of the environmental impacts by Life Cycle Assessment (LCA). Constr. Build. Mater. 2016; 125: 1142–1151.

[5] Christoforou E, Kylili A, Fokaides PA and Ioannou I. Cradle to site Life Cycle Assessment (LCA) of adobe bricks. J. Clean. Prod. 2016; 112: 443–452.

[6] Frota de Albuquerque Landi F, Fabiani C, D'Alessandro A, Ubertini F and Pisello AL. Life cycle assessment of a novel fired smart clay brick monitoring system for masonry buildings. Sustain. Energy Technol. Assessments. 2020; 50: 101745.

[7] Nouri H, Safehian M and Mir Mohammad Hosseini SM. Life cycle assessment of earthen materials for low-cost housing a comparison between rammed earth and fired clay bricks. Int. J. Build. Pathol. Adapt. 2023; 41(2): 364–377.

[8] Mohajerani A, Ukwatta A and Setunge S. Fired-clay bricks incorporating biosolids: Comparative life-cycle assessment. J. Mater. Civ. Eng. 2018; 30(7): 1–12.

[9] Ramos Huarachi DA, Gonçalves G, de Francisco AC, Canteri MHG and Piekarski CM. Life cycle assessment of traditional and alternative bricks: A review. Environ. Impact Assess. Rev. 2019; 80: 106335.

[10] Lozano-Miralles JA, Hermoso-Orzáez MJ, Martínez-García C and Rojas-Sola JI. Comparative study on the environmental impact of traditional clay bricks mixed with organic waste using life cycle analysis. Sustain. 2018; 10(8).